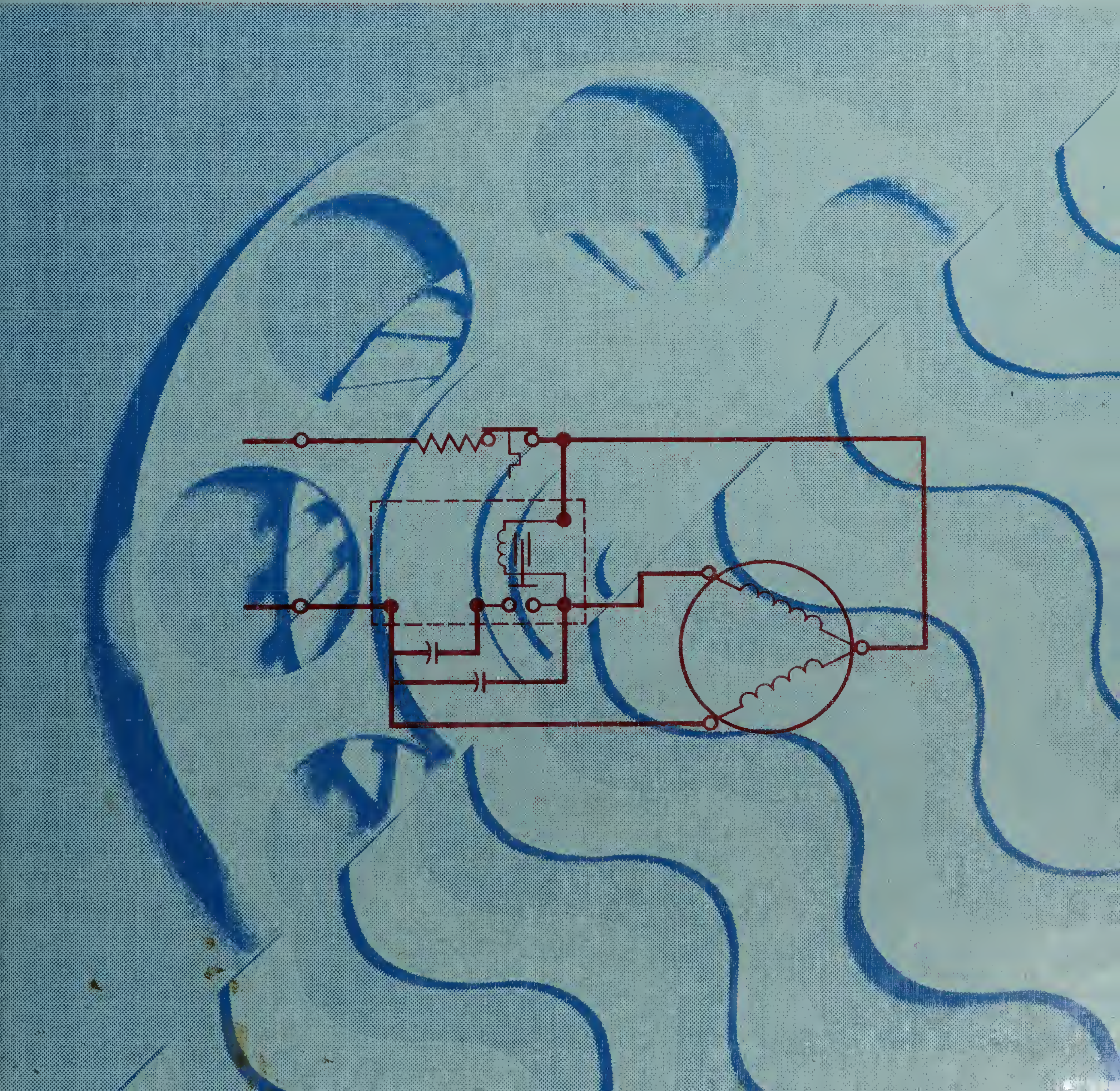
Basics of Electric Appliance Servicing

FUNDAMENTALS OF CIRCUITS, MOTORS, AND HEAT



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FUNDAMENTALS OF CIRCUITS, MOTORS, AND HEAT

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Contents

Preface

Because of its complexity, the study of electricity in all its phases requires months or even years of intensive effort. The intention of this book is to provide only sufficient coverage of the subject to convey its basic concepts to service technicians engaged in diagnosing and servicing both large and small appliances. The object is threefold. First, to remove some of the mystery which has always surrounded electricity in the minds of most people, thereby reducing the fear of it. Second, to familiarize service technicians with the purpose, construction, and operation of the various electrical components used in appliances, thereby increasing their proficiency. Third, to instill a desire to learn more about the subject by reading other textbooks and attending classes at the appliance manufacturers' training centers and at technical colleges.

Over the years there has been a considerable increase in the number of different types of products, especially in the field of appliances. This has necessitated an increase in the types of electrical components and devices required to operate them. In *Small Appliance Servicing Guide, Major Appliance Servicing,* and *Refrigeration, Air Conditioning, Range and Oven Servicing* (the three other books in this series), we cover specific appliances, but in the present volume, we fully cover the subject of basic electricity as it applies to appliances both large and small.

This book—as all the others in the series—was written with the full cooperation of the Association of Home Appliance Manufacturers (AHAM) and its Service Committee under the chairmanship of S. E. Upton of the Whirlpool Corporation. While the AHAM and all its members were most cooperative in the preparation of this book, we would especially like to thank the following for their outstanding help: C. H. Ramlow of Kelvinator; D. C. Shaffer and S. L. Gessaman of Fridgidaire; Guy Turner, V. A. Miller, and A. R. Sabin of Whirlpool; R. W. Rivett of Gibson, and Robert Holding of AHAM. A major portion of the text, as well as many of the illustrations, was taken from the following home study courses: *Basic Electricity for Appliances* (Whirlpool); *Practical Electricity* (Frigidaire); and *Basic Electricity* (Kelvinator). In addition, we want to thank Janet Just, who did the typing of the manuscript; Ronald L. Graffius of G. J. Bear Company, who reproduced a portion of the illustrations; and Mary Puschak, who coordinated all the art for this book.

Basics of Electric Appliance Servicing

Fundamentals of electricity

CHAPTER

1

Some knowledge of electrical fundamentals is required by the service technician for the testing, servicing, and repair of even the simplest electrical appliance. He must know some of the basic characteristics of electricity, electric conductors and insulators, and electric circuits and components. The more complicated the electrical appliance, the more knowledge the service technician must have to do an intelligent ser-

vicing job. The purpose of this book in our appliance training course is to familiarize service technicians with the basic principles of electricity utilized in electrical appliances.

To gain an understanding of electricity, we must have some knowledge of the electrical nature of matter, which means that we must understand the structure of atoms. Atoms are the tiny particles, having certain electrical characteristics, which make up all matter. Similarly, to understand how electric circuits operate, we must know what the functions of basic electric components used in the circuit are and how these components affect current flow. We must also be able to make observations with electrical measuring instruments.

Electricity is everywhere. Even the nerves in our bodies function, in effect, by electricity. The lightning flash in the sky and the northern lights are examples of electricity in nature. On a cold, dry day you may pass a plastic comb through your hair and notice a crackling sound—or your hair may even stand up straight. This is another example of electricity.

According to the earliest recorded history, electricity was first recognized about 600 B.C. when a distinguished Greek philosopher, Thales, noticed that amber, a yellow fossil resin, when rubbed would attract light bits of material such as lint and chaff. The Greek word for amber is *elektron.* Not until the beginning of the seventeenth century did important electrical developments take place. Around 1600 A.D. William Gilbert, English physician to Queen Elizabeth, listed several materials which acted like amber when rubbed, and he called these materials *electrics* because they behaved like *elektron* or amber. From this we get the word "electricity."

What is electricity? Electricity is a form of *energy.* Energy is the ability to do work, and is manifest in many different forms, one of which is electricity. Many people know about the effects of electricity, but few people attempt to understand its real nature. This we leave to the physicists and mathematicians. We are more concerned with what electricity does and how it is controlled.

DEFINITIONS OF ELECTRICAL TERMS

We see electricity, or electric energy, converted into many other forms of energy. We see it as light in an incandescent lamp or a fluorescent lamp. We see it as heat on an electric stove or in a toaster. We see it converted to motion in the spinning of a washer tub. Nearly all the labor-saving appliances found in the home are run by electricity.

In appliance servicing we work with electricity. We deal with electrical terms such as voltage, volts, current, amperes, power, watts, conductors, insulation, resistance, circuits, motors, generators, etc. These terms will be defined now so that everyone will know exactly what we are talking about. Other terms will be defined as we continue our study.

What Is Voltage?

Voltage is pressure, electric pressure. It may be likened to the water pressure in a water-distribution system. It is also a force, referred to as *electromotive force* (emf). Other terms used for voltage are *potential* and *potential difference.*

What Is a Volt?

The volt, which is abbreviated V, is the unit measure of voltage. The volt is a unit of electric pressure. Just as water pressure is measured in pounds, so electric pressure is measured in volts. The volt is defined as the potential difference between two points when a charge of one coulomb (C) either requires or uses up one joule (J) of energy in moving from one point to another. In more familiar terms, we may define the volt as the electromotive force needed to drive a current of one ampere (A) through a resistance of one ohm (Ω).

What Is Current?

Current is electricity in motion. Current is the flow of electrons through a conductor. The force (pressure) that drives the current is the electromotive force (voltage or potential differ-

ence). As in our water-system analogy, in which we see that the water pressure drives the water through the pipes, so the electric pressure drives the electrons along the conductor. Current flows only between points having a difference of potential. This potential difference must be maintained by a source, such as a generator, in order for a current flow to be continuous.

What Is an Ampere?

The ampere, abbreviated A, is a unit measure of current. It is a measure of the flow of electrons past any point during a specified interval of time. One ampere (A) is equal to the flow of one coulomb (C) per second (s). A coulomb is equal to about 6.28 billion billion electrons. When this many electrons flow past a single point in a single second we have an ampere of current.

What Is Power?

Power is the rate at which electric energy is generated or used. Power requires voltage and current, that is, electric pressure accompanied by a flow of electrons. Without voltage, there can be no current. Without current, no work can be done or energy used. Power is the product of voltage and current (volts × amperes).

What Is a Watt?

A watt, which is abbreviated W, is a unit of power. It is the measure of the rate at which electric energy is generated or expended. Considering direct-current (dc) power,

$$1\ \mathrm{W} = 1\ \mathrm{V} \times 1\ \mathrm{A}$$

In other words, with an applied voltage of 1 V and a current flow of 1 A, the resulting power is one watt. Power (P) may be computed by multiplying the voltage (E) by the current (I), where E is in volts, I is in amperes, and P is in watts; that is, $P = EI$. Power is expressed also in fractions of a watt, the milliwatt (mW), or thousandth of a watt, and in multiples of a watt, the kilowatt (kW), which is a thousand watts. In other words,

$$1{,}000\ \mathrm{mW} = 1\ \mathrm{W} \qquad \text{and} \qquad 1{,}000\ \mathrm{W} = 1\ \mathrm{kW}$$

Relating electric power to mechanical power, 746 W is equal to 1 horsepower (hp).

What Is a Kilowatthour?

The kilowatthour, abbreviated kWh, is a measure of the work done by electric power. It is the quantity of electric energy consumed. When we pay the power company for electricity, we are paying for the work done by the electric energy supplied by the company.

Work (W) is the amount of power (P) generated or consumed during a specific time period (t). It is power multiplied by time and is expressed as

$$W = Pt$$

When an electromotive force of 1 V maintains a current of 1 A for a period of one hour (h), the quantity of electric energy consumed is one watthour (Wh).

$$1\ \mathrm{Wh} = 1\ \mathrm{V} \times 1\ \mathrm{A} \times 1\ \mathrm{h}$$

or

$$\begin{aligned} 1{,}000\ \mathrm{Wh} &= 100\ \mathrm{V} \times 10\ \mathrm{A} \times 1\ \mathrm{h} \\ &= 200\ \mathrm{V} \times 1\ \mathrm{A} \times 5\ \mathrm{h} \\ &= 100\ \mathrm{V} \times 5\ \mathrm{A} \times 2\ \mathrm{h} \\ &= \text{(any combination that gives 1,000)} \\ &= 1\ \mathrm{kWh} \end{aligned}$$

Since "kilo" means one thousand, 1 kWh, as previously stated, is equal to 1,000 Wh.

What Is a Conductor?

A conductor is a material that supports current flow. We previously stated that current is the flow of electrons through a conductor. Electrons move more easily through some substances than through others. Those substances that permit easy flow are called conductors. Copper and aluminum are two of the best conductors. Metals, in general, make the best conductors because the atoms of the metallic elements contain numerous free electrons, a characteristic requirement of good conductors.

What Is an Insulator?

An insulator is a material that does *not* support current flow. Such materials are also referred to as *nonconductors* or *dielectrics.* They are lacking in free electrons and thus lack the requirement which is essential to the flow of electrons. Examples of insulators are glass, mica, rubber, ceramics, plastics, dry wood, dry paper, pure water, shellac, and dry fabrics.

What Is Resistance?

Resistance is the opposition to the flow of electrons, or current flow. All conductors offer some opposition to the flow of current, since there is no perfect conductor. Some offer more resistance than others.

In our water-distribution-system analogy, the flow of water through a pipe is slowed down by the friction between the water and the pipe. This friction, or resistance to flow, increases as the velocity increases. It is greater in small pipes than in large pipes for the same quantity flow, and it is proportional to the length of pipe; that is, it is twice as much in 100 ft of pipe as it is in 50 ft of pipe. In a similar fashion, the flow of electrons is slowed down by collisions with other electrons and with atoms. This reduction in flow is a loss of energy, which is converted into heat.

The resistance value of a conductor will depend upon (1) the nature of the material, particularly in regard to the number of free electrons it has; (2) the size of the conductor, as a larger gauge wire will permit more current flow than a smaller gauge wire; (3) the length of the conductor, as the longer the wire the greater will be the resistance to current flow; and (4) the temperature of the conductor. With a few exceptions, the resistance of a conductor increases as its temperature rises. Resistance is measured in *ohms.* The Greek letter omega, or Ω, is used to represent ohms.

What Is an Electric Circuit?

An electric circuit is a path or a group of interconnected paths capable of carrying electric currents. Three basic types of circuits are the *series* circuit, the *parallel* circuit, and the *series-parallel* circuit. The series circuit has only one path for the flow of current. The parallel circuit has two or more paths for flow of current. The series-parallel circuit is a combination of series circuits and parallel circuits. The circuit starts at the source of electricity and ends at the source of electricity. In this circuit, or path, there are usually one or more electrically operated devices, or electric components, termed *loads.*

What Is a Generator?

A generator is a mechanically operated rotating device that converts mechanical energy into electric energy. It is a machine that develops electric energy through rotary mechanical movement. The armature of a generator must be driven. Commercially, this is done by water power, by steam turbines or engines, or by diesel engines. The generator (also called an alternator) produces the electromotive force (emf), or electric pressure, that drives the electric current through the electric circuit.

What Is a Motor?

A motor is an electrically operated rotating device that converts electric energy into mechanical energy. It is a machine that develops power through rotary action. It must be supplied with electric current from an electric source, and when so supplied, it is able to do mechanical work.

ELECTRICAL NATURE OF MATTER

We define current as electricity in motion, as being the flow of electrons through a conductor. But what are electrons? To have a better understanding of what electrons are, and how they behave, we must study the nature of matter, and we must investigate the structure of atoms and their electrical characteristics.

Matter is anything that has weight and occupies space, and it may be classified as solid,

liquid, or gas. Matter is made up of small particles called *elements* and *compounds.* Elements are basic substances. Compounds contain two or more elements in chemical union. There are over 100 basic, or naturally occurring, elements. Chemical combinations of these natural elements make up hundreds of thousands of different compounds.

Elements. Elements are made up of smaller particles called *atoms.* The atoms in any particular element are identical. For example, all copper atoms are alike, but they differ from iron atoms or carbon atoms. The difference is in the number and arrangement of the smaller particles that make up the atoms.

According to scientific knowledge, the atom consists of a relatively heavy central core, called the *nucleus,* and one or more lighter particles, called *electrons.* The electrons travel around the nucleus in fixed paths or orbits, much as the planets in our solar system travel around the sun. The nucleus consists of one or more *protons* and most often has an equal number of *neutrons.*

Science has verified that the protons in the center core of the atom have a charge opposite to that of the electrons; by convention, the charge of proton particles is labeled "positive" (+), while that of electron particles is labeled "negative" (−). The "positive" charges balance the "negative" charges in the atom, so that the atom itself is normally neutral. What about the neutrons? They are *not* charged, but they do have the ability to hold the protons together in the nucleus.

The negatively charged electron is the same in any element or atom. The positively charged proton is the same in any element or atom. However, the different kinds of atoms and elements are made up of different quantities of these electrons, protons, and neutrons, and the manner in which they are arranged differs.

The structure of the hydrogen atom is the simplest of all. As illustrated in Fig. 1-1, it has one electron rotating in orbit around one proton as the nucleus. *Note:* The nucleus of the hydrogen atom, of course, also contains one neutron. In most instances, the number of neutrons in the nucleus of any atom is equal to the number of protons and also to the number of electrons in orbit. Since the neutrons are not charged and we are concerned primarily in this course with only the charged particles, no further reference to neutrons will be made.

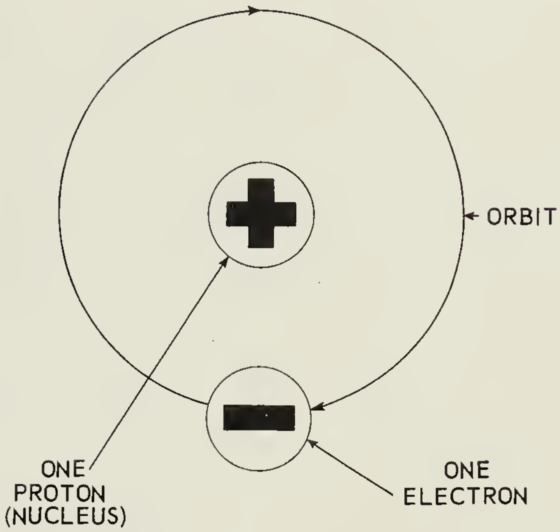


Figure 1-1. Diagram of a hydrogen atom.

While the structure of the hydrogen atom is relatively simple, the structure of the other atoms becomes more complex as the number of electrons and protons progressively increases. Helium has two protons in the nucleus and two electrons in orbit around it. Carbon has six protons in the nucleus and six electrons in orbit. This establishes a pattern for atoms: The number of protons in the nucleus is equal to the number of electrons in orbit, except in the special case of ions (to be discussed later).

An oxygen atom, as illustrated in Fig. 1-2, has eight protons and eight electrons. The electrons are divided into two groups with two electrons in an orbit near the nucleus and the other six in an orbit at a farther distance. As the number of electrons in the elements increases, the number and spacing of their orbits increases. For example, the 92 electrons in a uranium atom are divided into seven differently spaced orbits around the 92 protons in the nucleus. The chart here lists several of the more commonly known elements, with their atomic numbers and atomic weights. The atomic number for each

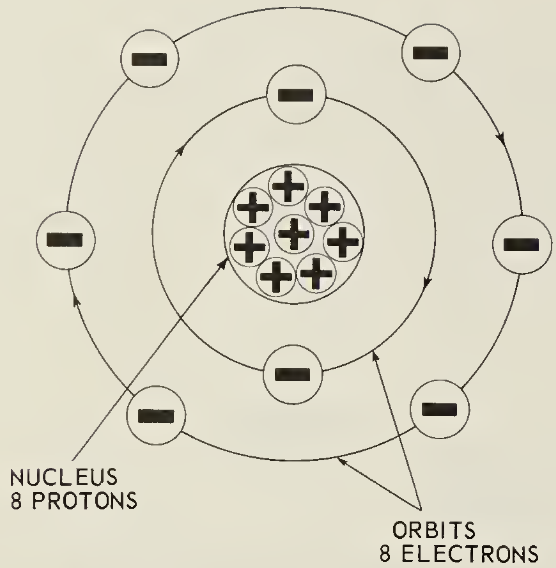


Figure 1-2. Diagram of an oxygen atom.

element is based on the number of electrons and protons it has. For instance, hydrogen has one electron and one proton. Therefore its atomic number is 1.

Element	Atomic number	Atomic weight
Hydrogen*	1	1.008
Helium*	2	4.003
Carbon	6	12.01
Nitrogen*	7	14.008
Oxygen*	8	16.00
Fluorine*	9	18.998
Aluminum	13	26.97
Chlorine*	17	35.453
Iron	26	55.85
Nickel	28	58.69
Copper	29	63.57
Silver	47	107.88
Tin	50	118.70
Gold	79	197.0
Mercury†	80	200.61
Lead	82	207.21
Uranium	92	238.07

* Gas
† Liquid

Compounds. Every known substance other than the elements is a compound. A compound is a substance which is made up of two or more elements. In a compound, two or more elements combine, chemically, to form a distinct substance with the same proportion of elements always present in its composition.

When an atom of one kind of element is combined with an atom of another kind, it forms a particle called a *molecule.* A molecule may be defined as the smallest particle of a compound which is of the same chemical composition as the compound itself.

The chemical formula for water, H_2O, is well known to most people. The formula indicates that the two elements hydrogen and oxygen are combined chemically, two atoms of hydrogen being present for every atom of oxygen. Figure 1-3 illustrates the fact that the smallest particle of water must contain two hydrogen atoms and one oxygen atom in order to retain the same chemical properties as water itself. The atoms are locked together due to the crossing of the orbits of the rapidly rotating electrons. Of course, it would require millions of these molecules to form one drop of water. All other compounds are built up in the same general manner.

Many compounds are composed of more than two elements. These would include all of the Freon refrigerants. For example, a molecule of Freon-12 (or R-12, as it is more frequently called) contains one carbon atom, two chlorine atoms, and two fluorine atoms all locked together by the rotating electrons. The chemical name for R-12 is *dichlorodifluoromethane.*

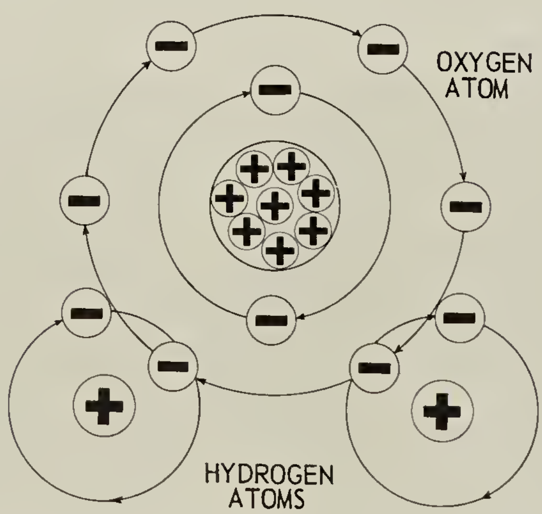


Figure 1-3. Diagram of a molecule of water (H_2O).

Electron movement. The relationship between the electrons and protons of an atom is the basis for the well-known facts that positive charges repel each other, negative charges repel each other, and positive charges attract negative charges. The attraction of the protons in the nucleus of an atom for the surrounding electrons holds the atom together. The strength of the attraction varies widely in the different atoms. As the distance from the nucleus at which the electrons orbit increases, the force of attraction between the nucleus and the electrons decreases proportionately. This is known as *Coulomb's law.*

Even though the atoms are locked together by the overlapping of orbits, some of the electrons are able to move from one atom to the next due to the weakness of attraction for their nucleus. These electrons are called *free* electrons. Other electrons are so close to the nucleus that the attraction is too strong to allow them to leave their orbit. These electrons are called *planetary* or *bound* electrons. According to the electron principle, electricity is the movement of free electrons from one atom or molecule to another. The force which causes them to move will be explained later. Figure 1-4 illustrates the combining of three carbon atoms. Because of its free electrons and other desirable characteristics, carbon is used as a conductor for electricity on many applications.

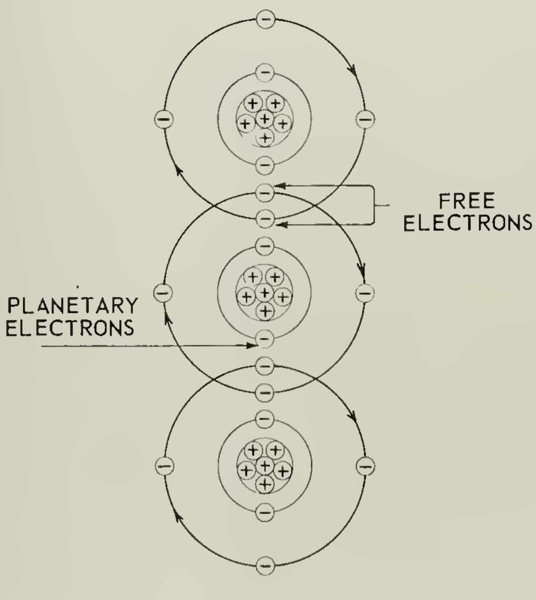


Figure 1-4. The combining of three carbon atoms.

From the foregoing, it is obvious that any substance with a great number of free electrons would be what we call a good *conductor* of electricity. Such substances as platinum, gold, silver, and tin each have many free electrons and make excellent conductors, but their cost and other characteristics make them more or less impractical for commercial use. In spite of its cost, however, silver is used extensively for electrical contacts in switches and contactors to ensure good electrical performance and give long, trouble-free service. Other substances such as copper, brass, aluminum, iron, tungsten, and nichrome are widely used either in the conduction of electricity from one place to another or in the construction of the multitude of electrical devices.

Conversely, there are many substances in which the force of attraction between the protons and the electrons is so strong that there are very few free electrons. These substances are called *insulators* and we say they have a *low conductance.* A few examples of good insulators are glass, slate, wood, mica, and plastic.

Ions. We mentioned previously that atoms are normally neutral and show no electric charge. However, if one or more electrons (−) are removed from an atom, an unbalanced condition will exist, as there are not enough negative charges (electrons) to balance the positive charge of the nucleus (+). The atom will show a positive charge and is referred to as a *positive ion.* In the same way, if an atom gains one or more electrons from the outside, it will have more negative charges than positive charges and will show a negative charge. It is referred to as a *negative ion.* The process of adding or removing electrons from atoms is called *ionization.*

SOURCES OF ELECTRICITY

Most of us are familiar with several kinds of electricity: static electricity, produced when a

plastic comb is passed briskly through the hair on a cold, dry day; dc electricity, produced by batteries, power cells, and the dc generator in the automobile; ac electricity, which operates our appliances and is produced by commercial power stations for general distribution throughout most of the world.

There are seven principal ways in which electricity is produced:

1. *Friction.* Friction between certain materials will generate static electricity.
2. *Chemical action.* Batteries generate a difference of potential by means of chemical action.
3. *Heat action.* Two dissimilar metals banded together in a junction will, when heated, produce a difference of potential. Such a junction is called a *thermocouple.* The electricity generated by heat action is called *thermoelectricity.*
4. *Light action. Photocells* are devices which convert light energy directly into electric energy. Light energy has the ability to knock free electrons out of the atoms of the photocell material. The process is called *photoelectricity.*
5. *Pressure.* Certain crystals, such as quartz, when squeezed or stretched show a difference of potential across the faces of the crystal.
6. *Magnetism.* Electricity in large commercial amounts is at present produced by rotating machines making use of *magnetism.* The machines are called *generators* and are turned by water power, wind, gas engines, diesel engines, steam engines, or steam turbines. Magnetism is our greatest and most important source of electricity today.
7. *Radioactivity.* Another source of electricity is the direct action of radioactivity. This source of electricity is not covered here because it is not encountered by the service technician.

Let us now take a more detailed look at the six sources of electricity with which we are concerned.

Electricity by Friction

As previously mentioned, electricity produced by friction is commonly called *static electricity,* and is produced by rubbing certain types of materials together.

The types of materials that are used in producing static electricity are called *dielectrics.* Dielectrics are actually insulators, such as glass, rubber, paper, and plastics, through which an electrical current will not normally pass. They do, however, contain some free electrons which can be transferred from one substance to another substance to create a shortage of electrons in one and an overabundance in the other, as we will explain later.

Due to the fact that static electricity cannot be harnessed to produce a steady flow of current, it has little practical application for the direct operation of appliances. We believe, however, that a knowledge of the subject is required in order to understand the basic construction and operation of a *capacitor*, or *condenser.* A capacitor is an electrical device that is essential to the operation of numerous appliances, as well as to radios, televisions, and automobiles.

You are familiar with many instances of static electricity. The spark which results when you touch a door knob after walking across a rug is the release of static electricity which has been developed by friction between your shoe and the rug. Lightning is static electricity produced by the friction between air and water particles. A cloud picks up electrons and then discharges them to another cloud or to the earth.

To understand lightning and other manifestations of static electricity we must accept the fact that the electrons and protons, of which all matter consists, are negative and positive charges, respectively. That is, when an amber rod or a hard rubber rod is rubbed with a piece of fur, for example, it becomes charged and will attract bits of paper, the same as a magnet attracts iron. What happens during the rubbing process is that free electrons are transferred from the fur to the rubber rod by friction. Thus, the rubber has a surplus of electrons, and since electrons

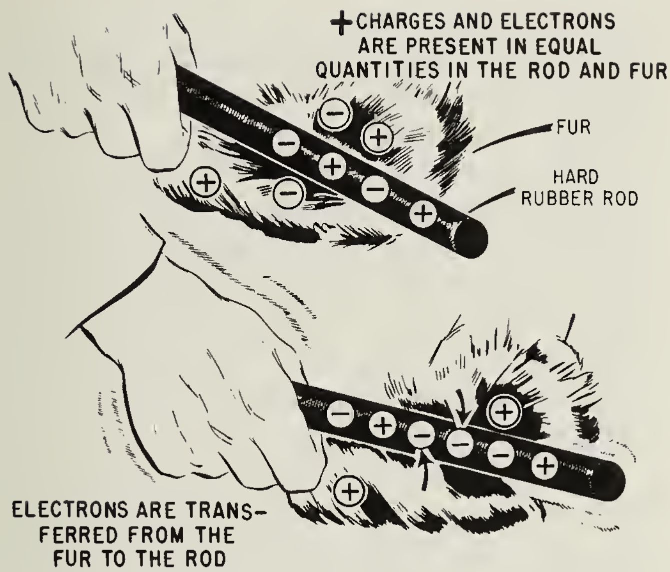


Figure 1-5. Producing static electricity by friction.

are always negatively charged particles, the rubber rod will have a negative charge (Fig. 1-5).

Rubbing a glass rod with a piece of silk removes free electrons from the glass rod, which are taken by the silk atoms. Thus the rod, being short of electrons, acquires a positive charge, and the silk atoms, having a surplus of electrons, takes on a negative charge. The energy with which these materials are charged is called *static electricity*, because it is motionless. It is also called *frictional electricity*, because the charge is generated by rubbing.

The charged body will retain the charge for a certain length of time, but eventually the charge will leak off. The body can be discharged quickly by touching it to ground.

A body that is charged with static electricity is surrounded by an electrostatic, or electric, field in which lines of force extend in every direction from the body. These lines of force are called *lines of dielectric flux* (Fig. 1-6). The strength of these lines of force diminishes rapidly as the distance from the body increases. When two bodies with like charges (+ and +) are brought close together, the lines of force oppose each other and do not meet. If the bodies have unlike charges (+ and −), the lines of force attract each other and many of the lines will extend from one charged body to the other. The flux lines start at the positive charge and end at the negative charge. Like charges repel each other. If two charges are both positive, they repel each other. If they are both negative, they repel each other. If one is positive and the other is negative, they attract each other.

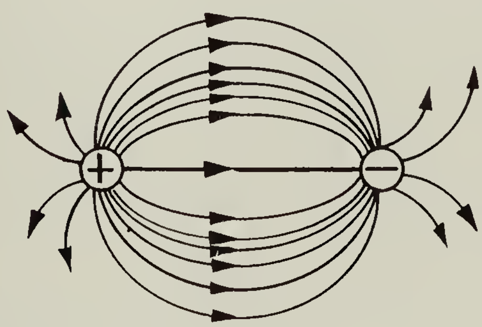


Figure 1-6. Lines of dielectric flux.

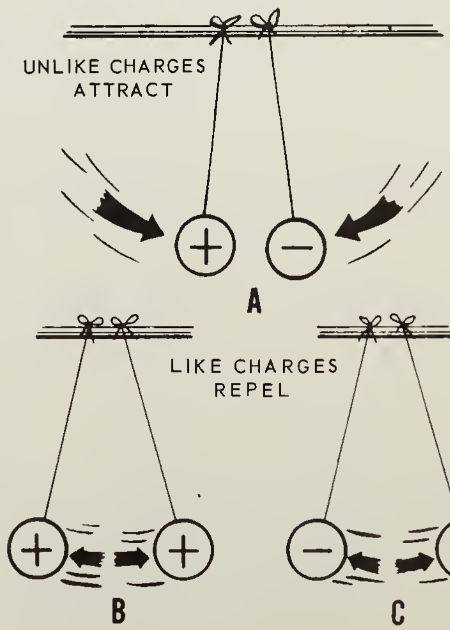


Figure 1-7. Reaction between charged bodies.

Thus, unlike charges attract each other. This is a basic phenomenon which is encountered in all applications of electricity. These two opposite kinds of electricity are referred to as positive and negative, and these conditions are termed *polarity*. Positive polarity is indicated by the plus sign (+) and negative polarity by the minus

sign (−). Polarity is encountered in all applications of electricity.

During our discussion of static electricity we have covered certain facts pertaining to its characteristics. We have demonstrated that a substance can be charged positively or negatively, temporarily or permanently, by induction or by conduction. Also, we demonstrated that positive charges repel positive charges, that negative charges repel negative charges, and that unlike charges attract each other.

Capacitor. Before leaving the subject of static electricity, it might be wise to mention the *capacity* that a substance has for storing a charge of electricity. The ability of substances to store charges of electricity is the basis of a condenser, or capacitor.

The principle of a capacitor involves the movement of electrons within two conductors which are insulated from each other, and incorporates an electric charge induced without contact. Figure 1-8 illustrates the construction of a simple capacitor. Two conductors, plates of metal or metal foil, are separated from each other by an insulator such as air, glass, wood, rubber, or paper.

The three factors which determine the capacity of a capacitor (the amount of current which may be stored in it) are the area of the metal or foil, the thickness of the dielectric, and the type of dielectric.

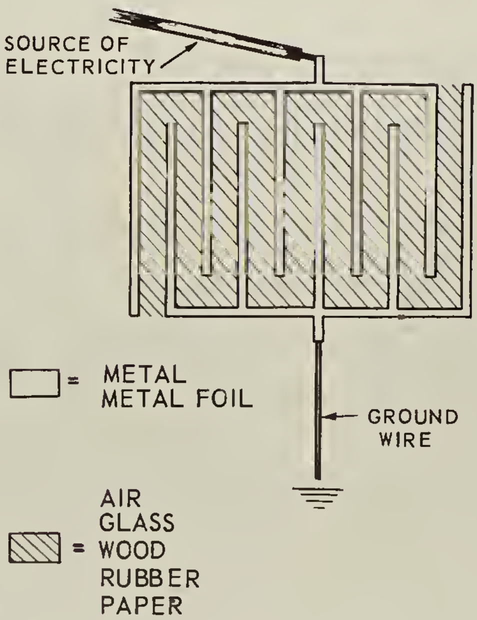


Figure 1-8. A simple capacitor.

For purposes of explanation, it will be assumed that, at the beginning, both plates or foil strips are in a neutral condition, with equal numbers of electrons and protons. If a negative charge of electricity is imposed upon the upper conductor, the electrons which pile up on it cause an equal number of electrons in the lower conductor to be repelled. To permit these repelled electrons to get away from the lower conductor, a wire to the ground is provided. The ability of the upper conductor to hold more electrons depends upon the number of electrons that are repelled to ground.

If the source of electricity and the path to ground were removed simultaneously, after a number of electrons had entered the upper conductor and repelled a like number from the lower conductor to ground; an unbalanced condition would be brought about. The upper conductor would have a surplus of electrons, while the lower conductor would have a shortage of electrons. A capacitor in this condition is said to be *charged*. Of course, if a path were provided, the surplus of electrons on the upper conductor would immediately pass to the lower conductor, neutralizing both.

The capacitors we are concerned with do not receive their charges by static electricity and are not connected to ground. They do, however, function on the same basic principles. Further information regarding capacitors will be given later in this book.

Grounding. What is meant by ground? Fortunately, the ground, or earth, has a tremendous ability to receive, dissipate, and, under some conditions, conduct electric charges without upsetting its electrical balance. Even the bolts of lightning which the earth receives have no more effect upon it than a raindrop would affect Niagara Falls.

The ability of the earth to receive electric charges plays a significant role in the generation, transmission, and utilization of electricity

in electric systems. Grounds can be both beneficial and harmful.

Intentional grounds are those in which a conductor is intentionally connected between a source of electricity and a cold-water pipe or a metal pipe driven into the ground. They also pertain to the connecting of a conductor between the metal frame of an electrical device and a point which leads to the ground. The purpose of intentional grounds is to protect property and electrical equipment against damage caused by lightning or accidental grounds. In either event, the ground wire keeps the rest of the electric system from being subjected to a charge of electricity greater than its capacity. Of equal, if not more, importance is the protection which a well-grounded system offers to personnel against electric shock and possible death. For these reasons, companies which generate and transmit electricity for public use usually provide numerous grounds between the generating plant and the points of utilization. With a few exceptions, the wiring systems in homes and buildings and certain types of electrical equipment installed therein are required to be intentionally grounded.

Accidental grounds are those in which a bare wire conducting electricity touches the frame of a device or appliance. This permits the electricity to take an unintended path and may result in damage to or malfunction of the device or serious injury to persons.

Further mention of grounds will be made during the course of this book.

Electricity by Chemical Action

Any device which produces electricity by chemical action is commonly called a *battery*. To understand how such a device produces electricity requires a knowledge of the substances used in the device and the chemical behavior of these substances.

Electrolytes. Nature stores up much energy in many chemical compounds. Due to the fact that the amount of energy stored is not the same in the various compounds, some are more desirable than others for use in batteries.

How the stored energy of compounds can be put to practical use is of considerable interest and is the basis of all battery operation. When certain acids or salts are dissolved in water, their molecules are broken up into positively and negatively charged particles called *ions*. As stated earlier in the chapter, an ion may be defined as an electrically charged atom or group of atoms. Any solution containing these ions is capable of conducting an electric current and is called an *electrolyte*. Even a solution of common table salt (sodium chloride) and water may be considered to be an electrolyte; the sodium atoms become positively charged ions, and the chloride atoms become negatively charged ions. Other solutions containing water and acids (such as hydrochloric acid and sulphuric acid) are capable of conducting more current than solutions containing water and sodium chloride. Water-acid solutions also have other more desirable characteristics for use in batteries.

Regardless of the type of solution, ions are capable of moving to every part of the solution.

Electrodes. In order to take advantage of the current-carrying properties of electrolytes, a battery must have *electrodes*, to which lights or other loads can be connected by wires or other conductors.

The chemical behavior of the electrolyte and the electrodes can best be explained from a simple voltaic cell, illustrated in Fig. 1-9. The term *voltaic* is applied to the cells of batteries in honor of Alessandro Volta, an Italian professor of physics who in 1796 produced the first storage battery.

The electrodes of a battery are made of *dissimilar metals*, that is, metals which have different chemical characteristics and which, when immersed together in an electrolyte, enter into a chemical reaction which produces electricity. Although various dissimilar metals can be used as electrodes, copper and zinc are excellent for the purpose. This is due to the fact that zinc contains an abundance of negatively charged atoms, while copper contains an abundance of positively charged atoms. When plates or rods of these metals are submerged into an electrolyte, chemical action between the two begins.

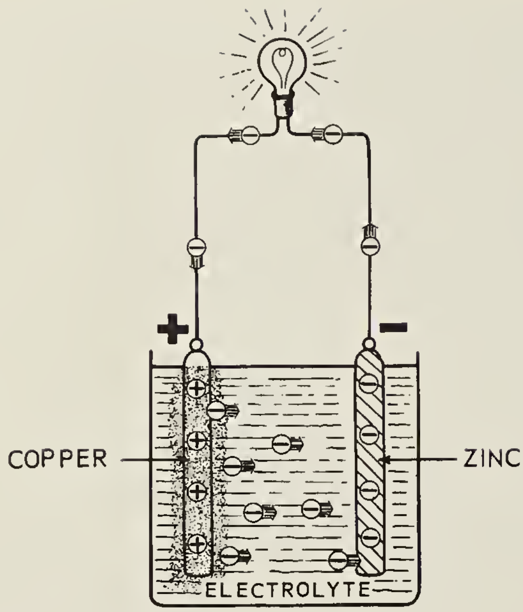


Figure 1-9. A typical voltaic cell—wet type.

The zinc electrode accumulates a much larger negative charge due to the fact that it gradually dissolves into the electrolyte solution. The atoms which leave the zinc during the process are positively charged. These positively charged zinc atoms are attracted by the negatively charged ions of the electrolyte. On the other hand, they repel the positively charged ions of the electrolyte which are then forced toward the copper electrode. This causes electrons to be removed from the copper, leaving it with a large excess of positive charge. If a load such as a light bulb is connected across terminals on the electrodes, the forces of attraction and repulsion will cause free electrons in the negative zinc electrode, connecting wires, and light bulb filament to move toward the positively charged copper electrode. When this happens, we say that a flow of current has been established.

Since the zinc electrode slowly dissolves, the life of a cell is limited. When an insufficient amount of zinc remains to provide the required chemical action, the cell is no longer capable of producing much electricity, and we say it is "dead."

Contrary to its name, a storage battery does not store electricity. It merely converts chemical energy into electric energy in accordance with the limitations of its ingredients.

The voltaic cell just described is known as a *wet cell* because of the aqueous, or water-based, solution used as the electrolyte. The instruments used for testing electric components during diagnosis procedures are equipped with one or more *dry cells.* A dry cell is not actually dry, because the electrolyte is a relatively moist paste. A cutaway view of a typical voltaic dry cell is shown in Fig. 1-10. From this we can see that the outer shell, which is made of zinc, also serves as the negative electrode. The positive electrode is made of carbon. Although the electrolyte is a paste and is made of different compounds than those used in wet cells, and although carbon is used instead of copper, the chemical action within the cell is similar to that within the wet cell and produces the same results. Both the wet and dry types of voltaic cells are called *primary cells* since they use up one of their primary ingredients. That is, a primary cell is one in which the chemical action eats away one of the electrodes, usually the negative one. When this happens, the electrode must be replaced or the cell must be discarded. In the *galvanic-type cell,* the zinc electrode and the liquid solution are usually replaced when this happens. In the case of the dry cell, it is usually cheaper to buy a new cell. Some primary cells have been developed that can be recharged.

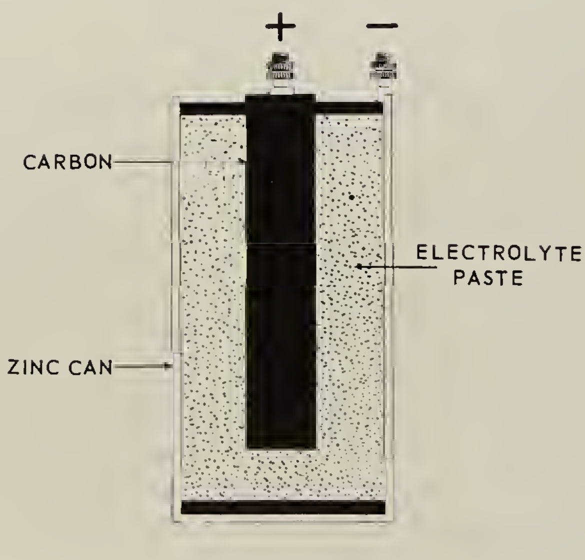


Figure 1-10. A typical voltaic cell—dry type.

Rating of the standard-size dry cell. One of the popular sizes of cell in general use is the standard, or No. 6, dry cell. It has an approximate diameter of $2\frac{1}{2}$ in and length of 6 in. The voltage is about $1\frac{1}{2}$ V when new but decreases as the eell ages. When the open-circuit voltage falls below 0.75 to 1.2 V (depending upon the circuit requirements), the cell is usually discarded. The amount of current that the cell can deliver, and still give satisfactory service, depends upon the length of time that the current flows. For instance, if a No. 6 cell is to bc used in a portable radio, it is likely to supply current constantly for several hours. Under these conditions, the eurrent should not exceed $\frac{1}{8}$ A, the rated constant-current capacity of a No. 6 cell. If the same cell is required to supply eurrent only occasionally and for only short periods of time, it could supply currents of several amperes without undue injury to the cell. As the time duration of each discharge deereases, and the interval of time between discharges inereases, the allowable amount of current available for each discharge becomes higher, up to the amount that the cell will deliver on short circuit.

The short-circuit eurrent test is another means of evaluating the condition of a dry cell. A new No. 6 eell, when short-circuited through an ammeter, should supply not less than 25 A. A cell that has been in service should supply at least 10 A if it is to remain in service.

Another popular size of dry cell, the size D, has a diameter of $1\frac{3}{8}$ in and a length of $2\frac{3}{4}$ in. It is also known as the *unit cell*, and it will be quickly recognized by anyone as the size used in popular flashlights. The size D cell voltage is 1.5 V when new. A discharged cell may expand, allowing the electrolyte to leak and cause corrosion. Some manufacturers place a steel jacket around the zinc container to prevent this action.

A eell that is not being used (sitting on the shelf) will gradually deteriorate because of slow internal chemical actions (local action) and changes in moisture content. However, this deterioration is usually very slow if cells are properly stored. High-grade cells of the larger sizes should have a shelf life of a year or more. Smaller cells have a proportionately shorter shelf life, ranging down to a few months for the very small sizes. If unused cells are stored in a cool place, their shelf life will be greatly increased; therefore, to minimize deterioration, they should be stored in refrigerated spaces (10 to 35°F) that are relatively humid (moist).

Reserve cells. A reserve cell is one in which the elements are kept dry until the time of use; the electrolyte is then admitted and the cell starts producing current. In theory, this means that a reserve dry cell should be able to be stored for an indefinite period of time before it is activated.

One new reserve cell (Fig. 1-11) is the alkaline manganese cell of the standard D size. This reserve cell exhibits a high efficiency over a wide temperature range and is capable of momentary high-current pulses in the range of 12 to 15 A.

The reserve cell is manufactured in a dry state, the electrolyte being eontained in a plastic vial within the cell. When stored in this dry state, the cell has a shelf-life capability of over 10 years. To activate the cell the activating mechanism is rotated 35° in either direction. This releases a spring-loaded plunger which breaks the plastic vial of electrolyte. Continued rotation permits the activating meehanism to be removed and discarded, resulting in an operating D size cell. A safety device prevents aecidental activation of the cell during handling and transit.

Figure 1-11. Typical reserve cells.

While primary cells are not used in modern household appliances, they do play an important role in the operation of several types of instruments required for properly diagnosing appliance trouble (see Chap. 8).

Secondary cells. Secondary cells operate on the same basic chemical principles as primary cells. They differ mainly in that they may be recharged, whereas the primary cell is not normally recharged. (As mentioned earlier, some primary cells have been developed that may be recharged.) Some of the materials of a primary cell are consumed in the process of changing chemical energy to electric energy. In the secondary cell, the materials are merely transferred from one electrode to the other as the cell discharges. Discharged secondary cells may be restored (charged) to their original state by forcing an electric current from some other source through the cell in the direction opposite to that of discharge.

The storage battery (Fig. 1-12) consists of a number of secondary cells connected in series. Properly speaking, this battery does not store electric energy, but is a source of chemical energy which produces electric energy. There are various types of storage cells—the lead-acid type, which has an emf of 2.2 V per cell; the nickel-iron alkali type, with an emf of 1.2 V per cell; the nickel-cadmium alkali type, with an emf of 1.3 V per cell; and the silver-zinc type, which has an emf of 1.5 V per cell.

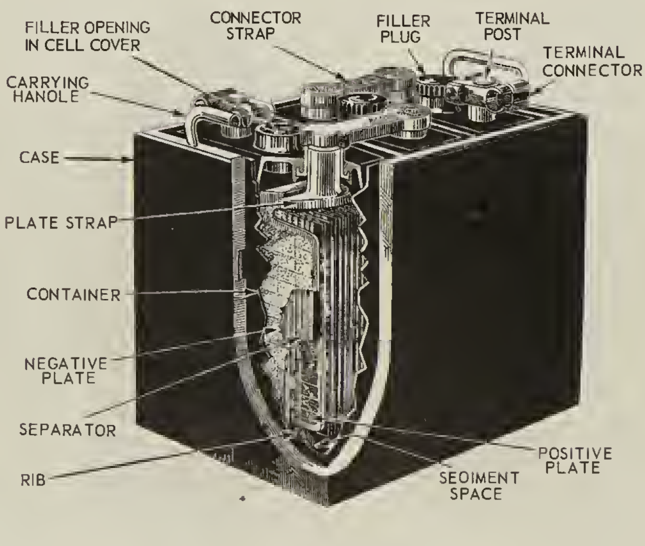


Figure 1-12. A typical storage battery.

No secondary cells are used in home appliances, except in the small, so-called "cordless" ones such as carving knifes, toothbrushes, and the like. In most of these small appliances, rechargeable nickel-cadmium (ni-kad) or silver-cadmium cells are employed. While most of these cells use potassium hydroxide as an electrolyte, the cells are sealed, so they do not ordinarily spill or leak the electrolyte. However, they are usually equipped with a vent to release the pressure in case the cell overheats. This can happen if the battery is improperly charged at an excessively high rate or if a defective battery—one that is internally shorted—is placed on charge. It is very important that you follow the charging rates recommended by the manufacturer. The charging rate has some effect on the life of the cell. Fast charging rates and deep discharges tend to shorten cell life. Details on the use of nickel-cadmium and silver-cadmium batteries and recharging procedures can be found in *Small Appliance Servicing Guide* (the second volume in this series).

Electricity by Heat

When a length of metal, such as copper, is heated at one end, electrons tend to move away from the hot end toward the cooler end. This is true of most metals. However, in some metals, such as iron, the opposite takes place and electrons tend to move toward the hot end. These characteristics are illustrated in Fig. 1-13. The negative charges (electrons) are moving through the copper away from the heat and through the iron toward the heat. They cross from the iron to the copper at the hot junction, and from the copper through the current meter to the iron at the cold junction. This device is generally referred to as a *thermocouple*.

Thermocouples have somewhat greater power capacities than crystals, but their capacity is still very small compared with some other sources. The *thermoelectric voltage* in a thermocouple depends mainly on the difference in temperature between the hot and cold junctions. Con-

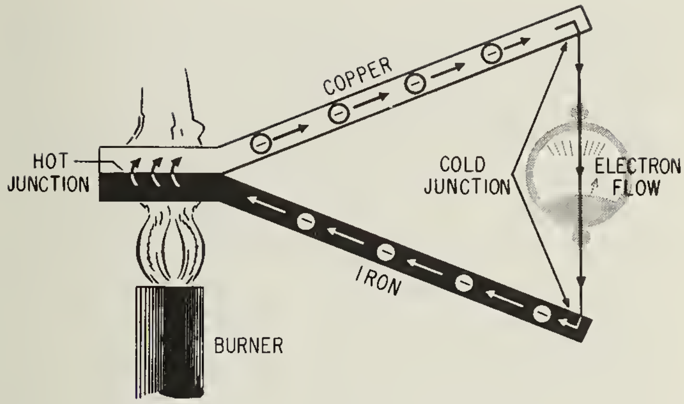


Figure 1-13. Voltage produced by heat.

sequently, they are widely used as thermometers and as heat-sensing devices in automatic temperature-control equipment. Thermocouples generally can be subjected to much greater temperatures than ordinary thermometers such as the mercury or alcohol types.

Electricity by Light

When light strikes the surface of a substance, it may dislodge electrons from their orbits around the atoms which are on the surface of the substance. This occurs because light has energy, the same as any moving force.

Some substances, mostly metallic ones, are far more sensitive to light than others. That is, more electrons will be dislodged and emitted from a more sensitive substance. Upon losing electrons, the photosensitive (light-sensitive) metal becomes positively charged, and an electric force is created. Voltage produced in this manner is referred to as a *photoelectric voltage.*

The photosensitive materials most commonly used to produce a photoelectric voltage are various compounds of silver oxide or copper oxide. A complete device which operates on the photoelectric principle is referred to as a *photoelectric cell.* There are many sizes and types of photoelectric cells in use, each of which serves the special purpose for which it was designed. Nearly all, however, have some of the basic features of the photoelectric cells shown here.

The cell (Fig. 1-14A) has a curved light-sensitive surface focused on the central anode. When light from the direction shown strikes the sensitive surface, the surface emits electrons toward the anode. The more intense the light, the greater is the number of electrons emitted. When a wire is connected between the filament and the back, or dark, side, the accumulated electrons will flow to the dark side. These electrons will eventually pass through the metal of the reflector and replace the electrons leaving the light-sensitive surface. Thus, light energy is converted to a flow of electrons, and a usable current is developed.

The cell (Fig. 1-14B) is constructed in layers. A base plate of pure copper is coated with light-sensitive copper oxide. An additional, semitransparent layer of metal is placed over the copper oxide. This additional layer serves two purposes:

1. It is *extremely* thin to permit the penetration of light to the copper oxide.
2. It also accumulates the electrons emitted by the copper oxide.

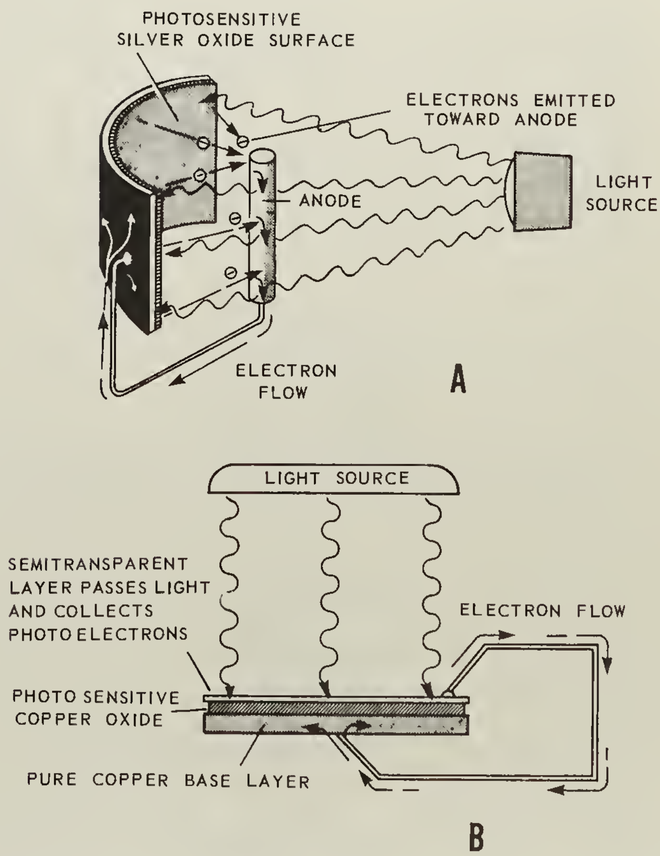


Figure 1-14. Voltage produced by light.

An externally connected wire completes the electron path, the same as in the reflector-type cell. The photocell's voltage is utilized as needed by connecting the external wires to some other device, which amplifies (enlarges) it to a usable level.

A photocell's power capacity is very small. However, it reacts to light-intensity variations in an extremely short time. This characteristic makes the photocell very useful in detecting or accurately controlling a great number of processes or operations. For instance, the photoelectric cell, or some form of the photoelectric principle, is used in television cameras, automatic manufacturing process controls, door openers, burglar alarms, and so forth.

Electricity by Pressure

This action is referred to as *piezoelectricity*. It is produced by compressing or decompressing crystals of certain substances. To study this form of electricity, the meaning of the word "crystal" must first be understood. In a crystal, the molecules are arranged in an orderly and uniform manner. A substance in its crystallized state and its noncrystallized state is shown in Fig. 1-15.

For the sake of simplicity, assume that the molecules of this particular substance are spherical (ball-shaped). In the noncrystallized state, in A, note that the molecules are arranged irregularly. In the crystallized state, B, the molecules are arranged in a regular and uniform manner. This illustrates the major physical difference between crystalline and noncrystalline forms of matter. Natural crystalline matter is rare; an example of matter that is crystalline in its natural form is diamond, which is crystalline carbon. Most crystals are manufactured.

Crystals of certain substances, such as Rochelle salt or quartz, exhibit peculiar electrical characteristics. These characteristics, or effects, are referred to as *piezoelectric*. For instance, when a crystal of quartz is compressed, as in C, electrons tend to move through the crystal as shown. This tendency creates an electric difference of potential between the two opposite faces of the crystal. (The fundamental reasons for this action are not known. However, the action is predictable, and therefore useful.) If an external wire is connected while the pressure and emf are present, electrons will flow. If the pressure is held constant, the electron flow will continue until the charges are equalized. When the force is removed, the crystal is decompressed and an electron flow occurs in the opposite direction, as in D. Thus, the crystal is able to convert mechanical force, either pressure or tension, to electric force.

The power capacity of a crystal is extremely

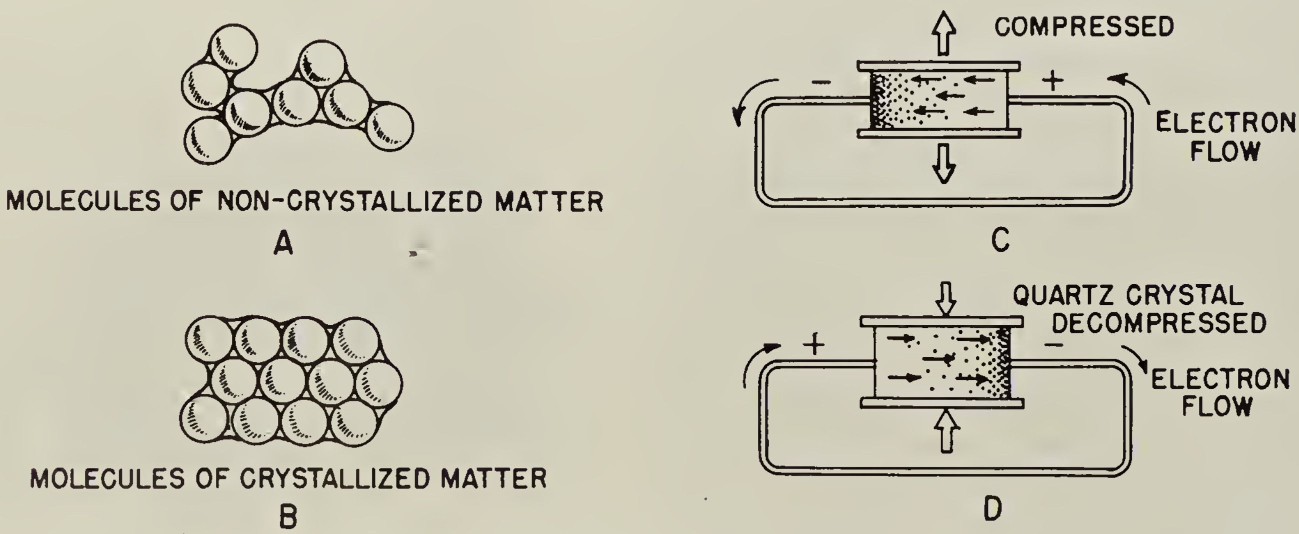


Figure 1-15. (A) Noncrystallized structure; (B) crystallized structure; (C) Compression of a crystal; (D) decomposition of a crystal.

small. However, crystals are useful because of their extreme sensitivity to changes of mechanical force or changes in temperature. Due to other characteristics not mentioned here, crystals are most widely used in communication equipment.

Electricity by Magnetism

As previously stated, the production of electricity by magnetism is of utmost importance to us since it is the greatest and most common source. Because of magnetism, electricity can be generated, transmitted, and distributed cheaply and in unlimited quantity to millions of homes, business establishments, and industrial plants.

In order to understand how magnetism can be made to work for us in many practical ways, it is necessary to have a basic knowledge of magnets. For instance, a substance is said to be a magnet if it has the property of magnetism—that is, if it has the power to attract such substances as iron, steel, nickel, or cobalt, which are known as *magnetic materials.* A steel knitting needle, magnetized by a method to be described later, exhibits two points of maximum attraction (one at each end) and no attraction at its center. The points of maximum attraction are called *magnetic poles.* All magnets have at least two poles. If the needle is suspended by its middle so that it rotates freely in a horizontal plane about its center, the needle comes to rest in an approximately north-south line of direction. The same pole will always point to the north, and the other will always point toward the south. The magnetic pole that points northward is called the *North pole*, and the other the *South pole.*

A magnetic field exists around a simple bar magnet. The field consists of imaginary lines along which a magnetic force acts. These lines emanate from the North pole of the magnet and enter the South pole, returning to the North pole through the magnet itself, thus forming closed loops.

A magnetic circuit is a complete path through which magnetic lines of force may be established under the influence of a magnetizing force. Most magnetic circuits are composed largely of magnetic materials in order to contain the magnetic flux. These circuits are similar to the electric circuit, which is a complete path through which current is caused to flow under the influence of an electromotive force.

Magnets may be conveniently divided into three groups:

1. *Natural magnets*, found in the natural state in the form of a mineral called *magnetite.*
2. *Permanent magnets*, bars of hardened steel (or some form of alloy such as alnico) that have been permanently magnetized.
3. *Electromagnets*, composed of soft-iron cores around which are wound coils of insulated wire. When an electric current flows through the coil, the core becomes magnetized. When the current ceases to flow, the core loses most of its magnetism.

Permanent magnets and electromagnets are sometimes called *artificial magnets* to further distinguish them from natural magnets, and are discussed in this chapter under the heading of Artificial Magnets.

Natural magnets. For many centuries it has been known that certain stones have the ability to attract small pieces of iron. Because many of the best of these stones (natural magnets) were found near Magnesia in Asia Minor, the Greeks called the substance *magnetite*, or *magnetic.*

Before this, the ancient Chinese had observed that when similar stones were suspended freely, or floated on a light substance in a container or water, they tended to assume a nearly north-and-south position. Probably Chinese navigators used a bit of magnetite floating on wood in a liquid-filled vessel as a crude compass. At that time it was not known that the earth itself acts like a magnet, and these stones were regarded with considerable superstitious awe. Because bits of this substance were used as compasses, they were called *loadstones* (or *lodestones*), which means "leading stones." Natural magnets are also found in the United States, Norway, and Sweden. A natural magnet, demonstrating the attractive force at the poles, is shown in Fig. 1-16A.

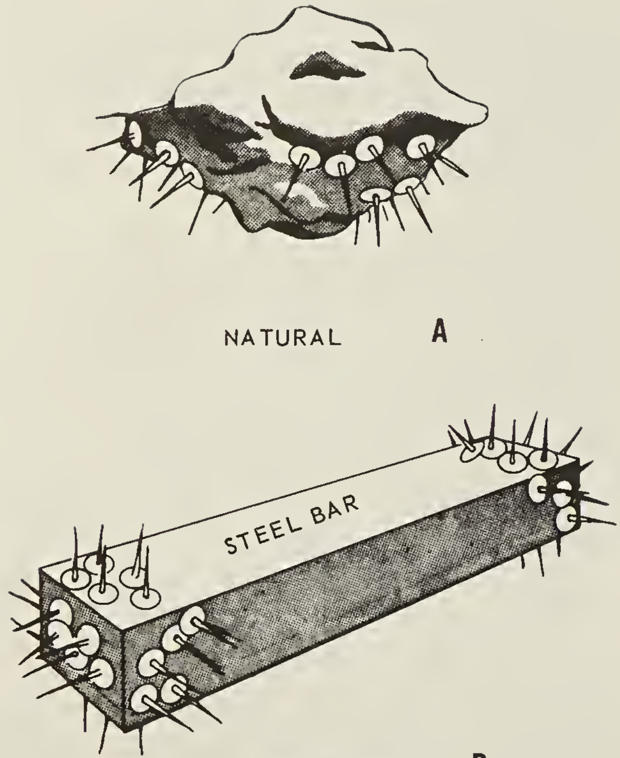


Figure 1-16. (A) Natural magnet; (B) artificial magnet.

Artificial magnets. Natural magnets no longer have any practical value because more powerful and more conveniently shaped permanent magnets can be produced artificially. Commercial magnets are made from special steels and alloys—for example, alnico, an alloy made principally of aluminum, nickel, and cobalt. The name is derived from the first two letters of the three principal elements of which it is composed. An artificial magnet is shown in Fig. 1-16B.

An iron, steel, or alloy bar can be magnetized by inserting the bar into a coil of insulated wire and passing a heavy direct current through the coil, as shown in Fig. 1-17A. This aspect of magnetism is treated later in the chapter. The same bar may also be magnetized if it is stroked with a bar magnet, as shown in Fig. 1-17B. It will then have the same magnetic property as the magnet used to induce the magnetism—namely, there will be two poles of attraction, one at either end. This process produces a permanent magnet by induction—that is, the magnetism is induced in the bar by the influence of the stroking magnet.

Artificial magnets may be classified as "permanent" or "temporary" depending on their ability to retain their magnetic strength after the magnetizing force has been removed. Hardened steel and certain alloys are relatively difficult to magnetize and are said to have a *low permeability* because the magnetic lines of force do not easily permeate, or distribute themselves readily through, the steel. (Permeability is a measure of the relative ability of a substance to conduct magnetic lines of force as compared with air. It is discussed in greater detail later in this book.) Once magnetized, however, these materials retain a large part of their magnetic strength and are called *permanent magnets.* Permanent magnets are used extensively in electric instruments, meters, telephone receivers, permanent-magnet loudspeakers, and magnetos. Conversely, substances that are relatively easy to magnetize—such as soft iron and annealed silicon steel—are said to have a *high permeability.* Such

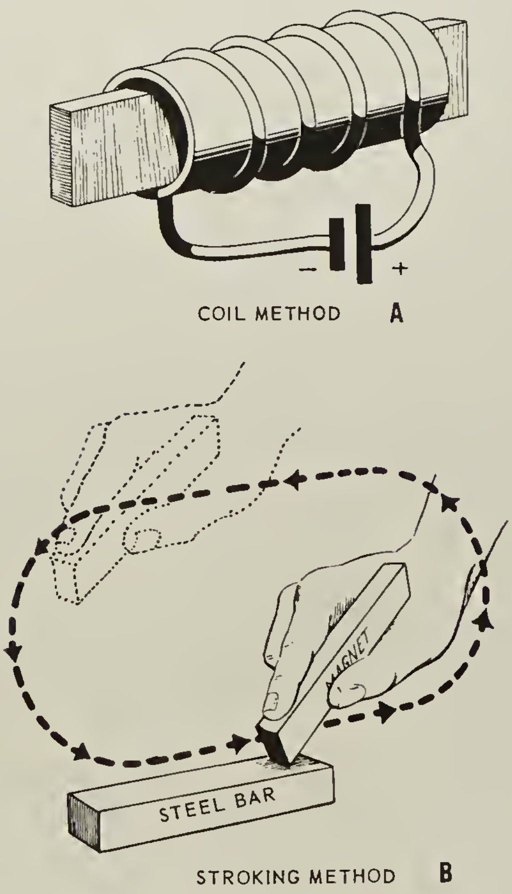


Figure 1-17. Methods of producing artificial magnets.

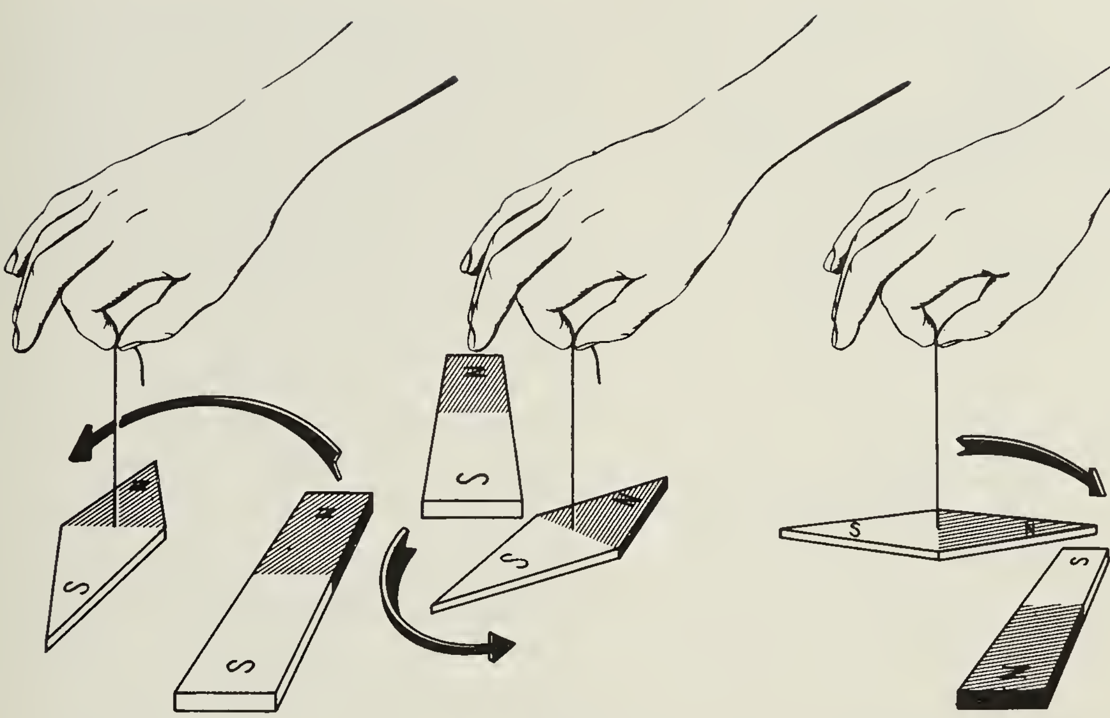


Figure 1-18. Laws of attraction and repulsion.

substances retain only a small part of their magnetism after the magnetizing force is removed and are called *temporary magnets.* Temporary magnets such as silicon steel and similar materials are used in transformers where the magnetism is constantly changing and in generators and motors where the strength of the fields can be readily changed.

The magnetism that remains in a temporary magnet after the magnetizing force is removed is called *residual magnetism.* The fact that temporary magnets retain even a small amount of magnetism is an important factor in the buildup of voltage in self-excited dc generators.

Properties of magnets. The reason an unmagnetized piece of iron is attracted to a magnet, as was stated earlier, is because of magnetic induction. For example, a nail can be sufficiently magnetized to attract and hold iron filings even though it is not in direct contact with the permanent magnet. This is one of the most significant of all factors in the production and utilization of electricity by magnetism.

Also, as mentioned previously, every magnet has two poles, a north-seeking pole or N pole, and a south-seeking pole or S pole. This fact can be readily proved by stroking a common needle with a magnet and floating the needle on a piece of straw in a pan of water. One end of the needle will turn toward the north. The end of the magnet which points toward the north is the N pole of the magnet. Also, the fact that a magnet has poles can be readily proved by dipping a bar magnet into a quantity of iron filings. The filings will cling in tufts to both ends of the bar but scarcely any will be observed in the center.

Another property of magnets is their ability to repel and attract each other. Like poles repel and unlike poles attract. If the N poles of two bar magnets were put together, they would jump apart, but, if the N pole of one is placed to the S pole of the other, they will hold fast together. This can be proved by holding one end of a bar magnet close to the end of a suspended bar magnet. If the two ends are of like polarity, the end of the suspended bar will move away from the end of the bar being held. If the polarity

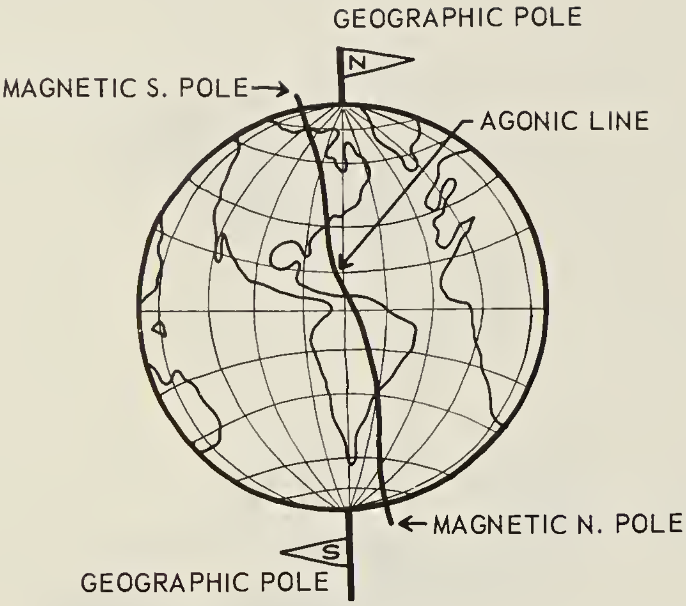


Figure 1-19. Earth's magnetic poles.

is different, the end of the suspended bar will move toward the other magnet.

The earth—a magnet. It can be proved that the earth itself is a magnet. This explains the fact that a magnetized object, such as a compass needle, always points approximately north and south. It has been discovered that there is a magnetic S pole near the north geographic pole and a magnetic N pole near the south geographic pole. Inasmuch as the North pole of a compass points to the north and it is known that like poles repel each other, it is logical to assume that the magnetic pole in the north is S.

The magnetic S pole near the north geographic pole was discovered in 1831 by Sir James Ross. Its location was 70°30′N latitude and 95°W longitude, which is in the north-central part of Canada, about 1,400 mi from the geographic pole. However, in 1905 Captain Roald Amundsen located it a little further west at 70°5′N and 96°46′W. From these and other observations it is believed that the earth's magnetic poles slowly shift their position.

Inasmuch as the magnetic and geographic poles are separated, a compass needle does not always point true north and south, and its direction changes as the compass is moved from one place to another on the earth's surface. The number of degrees by which the needle varies from true north and south is called the *angle of declination.*

On the *agonic line*, which is an imaginary line encircling the earth from one magnetic pole to the other, a compass will point true north and south and the angle of declination will be zero. This line is shown in Fig. 1-19.

The earth's magnetic lines are not all parallel to its surface. The angle between these lines and the earth's surface is known as the *dip* or *inclination.* The inclination can be readily determined by thrusting an unmagnetized knitting needle through a cork and thrusting another needle through the cork at right angles to the first. Support the apparatus on two objects with one needle acting as an axis and pointing east and west. By means of a bent pin or wax, balance the weight of the first needle until it is parallel with the table. Next, magnetize this needle by stroking the north end from the cork out with the N pole of a strong magnet and, in a like manner, the south end of the needle with the S pole of the magnet. It will be noted that the north end of the needle will dip or incline toward the table. The angle of inclination will depend upon how far north of the magnetic equator the experiment is being performed. At the magnetic equator there will be no dip. At the magnetic pole the angle will be 90°. In Chicago the angle of inclination is 72°50′.

Magnetic lines of force. The fact that magnets have the properties of repulsion and attraction indicates that lines of force are prevalent through and about them. In 1830, Michael Faraday introduced the idea that the magnetic lines of force passed in a curved line from the N pole of a magnet around the outside to the S pole and on the inside of the magnet from S back to N.

This can be proved as follows. Place a bar magnet beneath a pan of water. Place a cork with a magnetized needle through it in the water near the N pole. The cork will move in a curved path from N to S. This is due to the fact that the forces of repulsion and attraction are con-

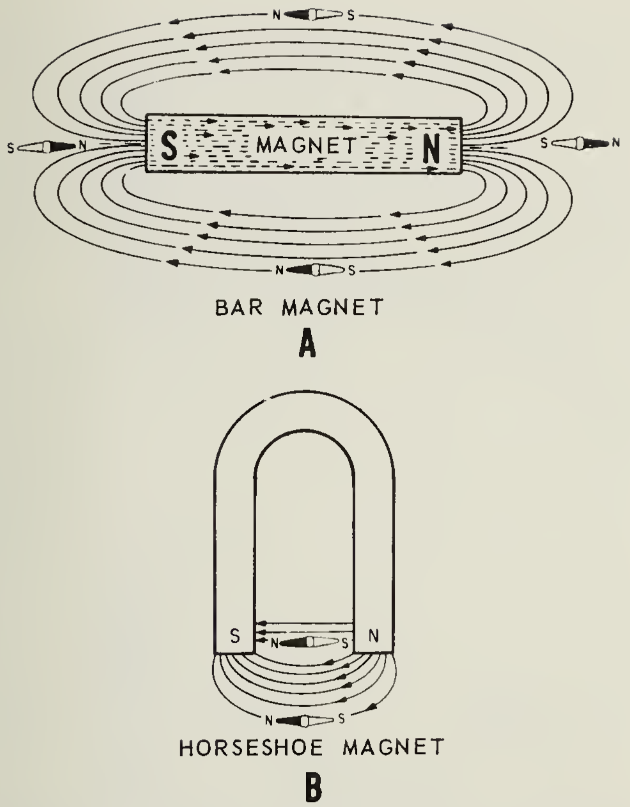


Figure 1-20. Magnetic field patterns around (A) a bar magnet and (B) a horseshoe magnet.

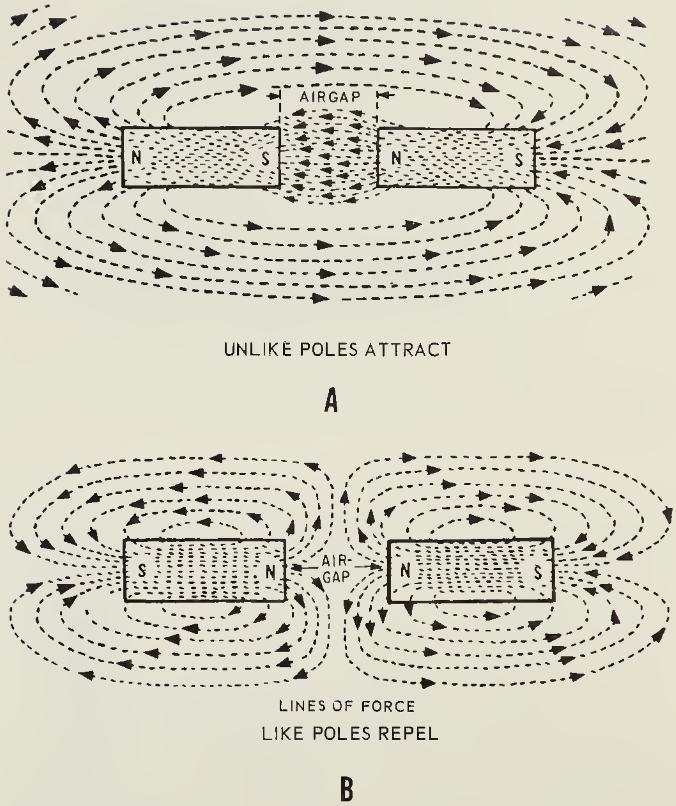


Figure 1-21. Lines of force between (A) unlike and (B) like poles of a bar magnet.

tinually changing as the relative distance of the moving pole changes.

Field of flux. The region surrounding a magnet in which its magnetic force can be detected is known as the *magnetic field of force*, shown in Fig. 1-20. This field is also known as the *field of flux*. There are three important facts that should be noted. First, none of the lines of force cross each other. Second, all lines are complete. Third, all lines leave the magnet at right angles to the magnet. Lines of force in a magnetic field may be seen by sprinkling iron filings on a piece of paper placed above a bar magnet.

Earlier in our discussion of magnetism, we mentioned the fact that like poles of a magnet repel each other while unlike poles attract. Now let us discuss repulsion and attraction briefly again as to the field of force or flux pattern produced. Figure 1-21A illustrates the lines of force produced when two unlike poles are placed near each other, while Fig. 1-21B illustrates the lines of force when two like poles are placed near each other. We can see that the unlike poles attract each other, while the like poles attempt to repel each other. This can be readily seen by placing a piece of paper over the ends of two bar magnets, sprinkling iron filings over the area above the magnets, and observing the pattern made by the filings. One of the magnets should then be reversed and the change in pattern observed.

Magnetizing a substance. From what we have learned thus far, we can assume that every atom and molecule of a magnetic substance has a North and South pole. Each is a tiny magnet. In a piece of unmagnetized iron the molecules are jumbled together as illustrated in Fig. 1-22A, which shows the N poles in black and the S poles in white. They cancel each other's force. If we stroke a magnet along the piece of iron, the strong N pole of the magnet attracts the S poles in the iron, causing some of the molecules to shift so that the S poles point to the N pole of the magnet. After each stroke, more and more

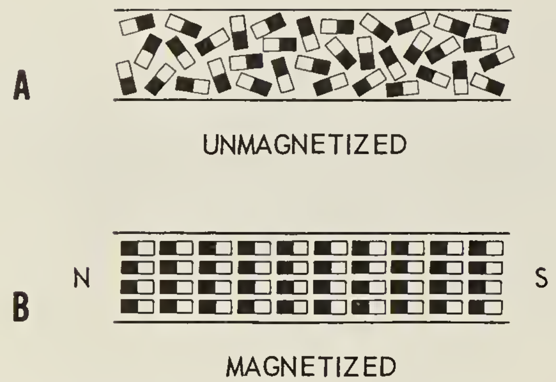


Figure 1-22. Molecular arrangement of iron.

of the molecules are found to have shifted, so that after sufficient stroking, all of the S poles are pointing in the same direction as illustrated in Fig. 1-22B.

When inducing magnetism, more strokes will produce more magnetism. However, there is a limit to how much any substance can be magnetized. When all the molecules are lined up as illustrated in Fig. 1-22B, we say that the magnet is *saturated.*

There are other properties and characteristics of magnetism; however, we have covered the common and important points that have a direct bearing on the subject of electromagnetism, which is discussed later in Chap. 3.

Induced voltage and current. Having discussed some of the characteristics of magnets and their effect on metals that are capable of being magnetized, we now discuss the effect of a magnetic field on metals that are nonmagnetic in nature. It is the effect of magnetic fields on nonmagnetic metals that makes possible the generation of current and its practical application to the numerous electric components used in many electrical appliances.

If a conductor is passed through a magnetic field, a voltage is induced in the conductor. The drawing here, Fig. 1-23A, illustrates a horseshoe magnet, a metal conductor such as a piece of copper with a copper wire attached at both ends, and a galvanometer in the circuit. The galvanometer is an instrument for measuring very small currents. As the conductor is moved in a downward motion through the magnetic field of flux, an electric current is induced in the conductor and wires. The direction of the current is indicated by the arrows, and the amount of current is indicated on the galvanometer. Actually, it is not current that is induced. What really happens is that the transfer of some of the magnetic energy to the conductor forces the electrons in the conductor to flow.

In Fig. 1-23B, the conductor is moving in an upward direction, and the needle of the galvanometer has moved in the opposite direction, indicating that the current has reversed its direction. Although a flow of current is obtained while the conductor is in motion, the flow ceases when the motion stops. The direction of the induced current depends on the direction in which the flux is cut.

Of course, the direction of the induced current is also determined by the direction of the field of flux. For example, in C the conductor is being moved in a downward direction. The N pole is on the left and the magnetic flux is to the right. The induced voltage is to the rear as indicated by the arrow. In D the magnetic poles and field have been reversed, and, while the conductor is still cutting the field in a downward motion, the induced voltage is reversed.

An important point to remember regarding induced current in a conductor is the fact that the strength of the current is determined by the position of the conductor in the field. For example, as the conductor enters the field, the flow is weak, but it increases to its maximum as the conductor reaches the center of the field. The current diminishes as the conductor leaves the field.

It stands to reason that the stronger the field, the stronger the current and the voltage will be. Therefore, if the poles of the magnet are increased in magnetic strength, the wire cuts more lines of flux and a stronger voltage is induced. How the magnetic strength of the poles is increased will be explained later in the book.

Since the amount of voltage induced is determined by the number of lines of flux cut per second, a higher voltage can be induced in three ways. First, the moving conductor can be

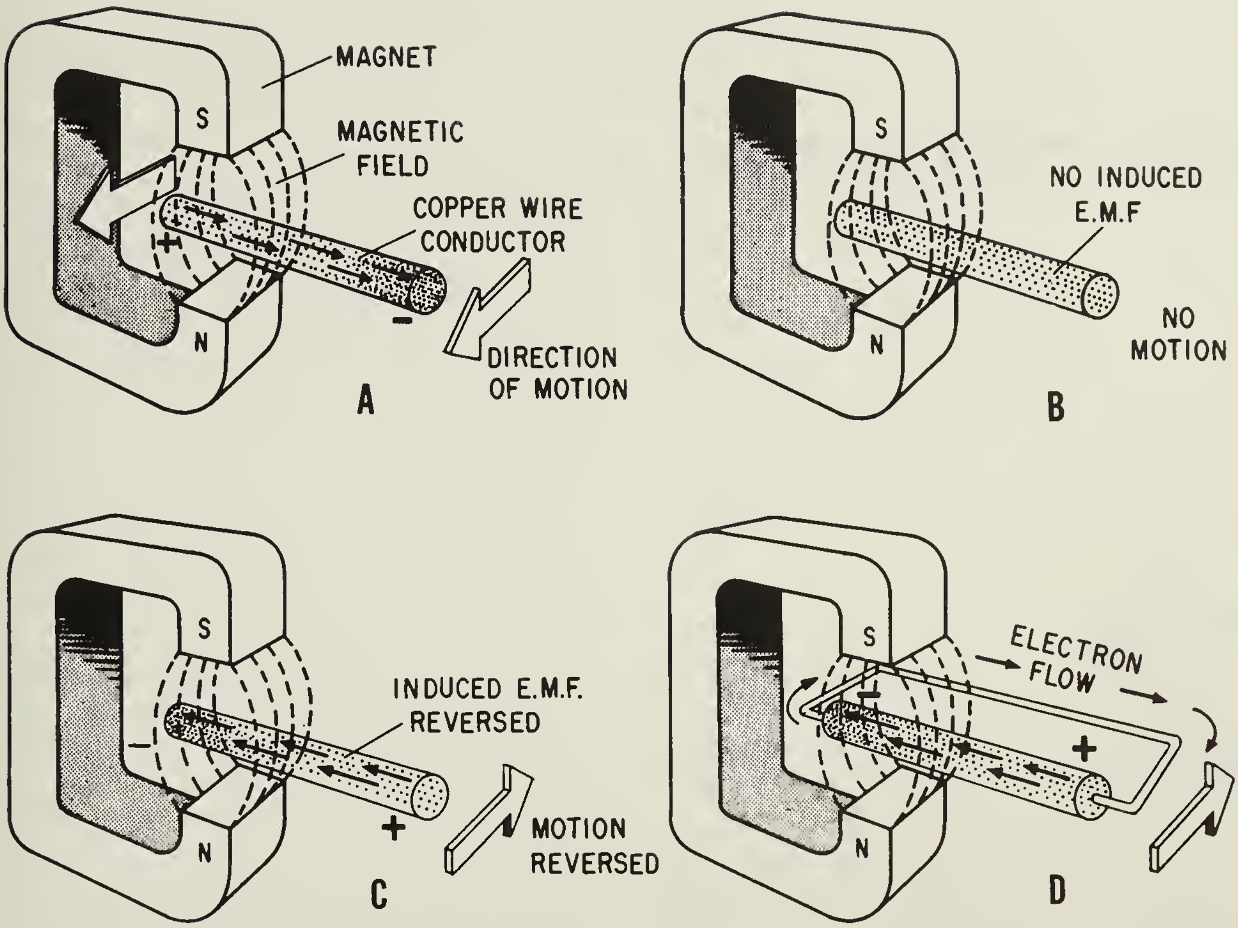


Figure 1-23. Voltage produced by magnetism.

speeded up; second, the magnetic strength can be increased; third, the conductor can be coiled so that more turns of wire cut the field. These three factors play an important part in the construction and design of motors and generators.

The basic principle of conductors cutting a magnetic field can now be applied to generators and motors. As stated before, although generators appear to be fairly simple in construction, they are sometimes quite complex in design. Inasmuch as this is a basic course, the discussion will be confined to the simplest of generators and motors.

In principle, generators and motors are identical. They are both classified as *dynamos*. If the shaft of a dynamo is connected to a prime mover, such as a turbine, and when turned, it pumps electricity out, it is a generator. But, if the same arrangement takes power in, it is called a motor. In other words, a generator produces current; a motor utilizes current.

The study of electricity and magnetism and how they interact with each other is given more thorough coverage in later chapters in this book. The discussion of magnetism up to this point has been mainly intended to clarify terms and meanings, such as "polarity," "fields," "lines of force," etc.

Dc circuits

CHAPTER

2

When a load, such as a light bulb, is connected to a battery, the flow of current is always in the same direction: from negative to positive terminals. Because it is flowing in only one direction and is flowing at an unfluctuating and steady rate, it is called *regular direct current*. How other types of current are produced will be described later. The flow of regular direct current can be compared with the flow of water produced by a centrifugal pump.

ELECTRIC CURRENT

The factors that affect the movement of water in a piped system can also be applied to the movement of electrons in an electric circuit. They are *pressure*, *quantity*, *rate of flow*, and *resistance*.

Pressure is the force that moves water through pipes. It is also the force that moves electrons through conductors. Just as the pump produces water pressure, the battery produces electric pressure. Quantity is in one case the amount of water moved by the pump, and in the other it is the amount of electrons moved by the battery.

Rate of flow is the speed or the strength of flow of water through the pipes and of electrons through the conductors. Resistance is the opposition produced by the pipes and fittings to the flow of water as well as the opposition produced by the conductors to the flow of electrons. Just as the pump must produce a sufficient pressure to overcome the resistance in order to move a unit quantity of water through a pipe, so must the battery produce a sufficient pressure to move a unit quantity of electrons through a conductor.

Each of these four factors as they pertain to electricity require further explanation.

Pressure

As stated in Chap. 1, the flow of electrons along a conductor when an electromotive force is applied constitutes an electric current. As we know, the free electrons in an atom are those which are farthest from the nucleus and which can be forced out of the atom, either repelled by a strong negative charge or attracted by a strong positive charge. If a difference in potential is applied between the two ends of a copper wire (see p. 2), the electric pressure or emf (voltage) will produce a drift of electrons along the wire. This can be illustrated by connecting the positive electrode of a battery to, say, the right end of a copper wire, and the negative electrode to the left end of the wire. The positive electrode, being short of electrons, will draw electrons from the atoms in the right end of the wire. These atoms then become positive ions since they are short of electrons. They will then attract free electrons from their neighboring atoms on the left, which in turn also become positive ions and attract free electrons from *their* neighbors on the left. This action continues along the wire, with electrons drifting successively from atom to atom until finally the atoms in the left end of the wire become positive ions and attract electrons from the negative electrode of the battery. As indicated, the electrons drift through the wire from the negative electrode to the positive electrode. Removing the battery electrodes removes the electromotive force, and the drift of electrons stops.

The electron drift is the basis of current flow. It is most pronounced in metals because metals have the largest number of free electrons to contribute to the flow. The flow of electrons always takes place between points which are at different potentials, and it always goes from the negatively to the positively charged body. The positively charged body is the point of higher potential. The potential of the earth is zero (0). If a positively charged body is connected to the earth, electrons flow from the earth to the positively charged body. If a negatively charged body is connected to the earth, electrons flow from the body to the earth, since the negative quantity is lower than zero.

A battery, by chemical action, produces negatively and positively charged particles which react with the negatively charged zinc electrode and the positively charged copper electrode. When a load is connected across the terminals, the unbalance in charges produces a pressure called an electromotive force (emf) which causes free electrons (current) to flow through the circuit. Actually, this flow of current is many billions of free electrons repelling each other throughout the conductor. As previously stated, the direction of force is always from the negative electrode to the positive one. Thus, as shown in Fig. 2-1A, current flow in the external circuit is the movement of electrons in the direction indicated by the arrows (from the negative terminal through the lamp to the positive terminal).

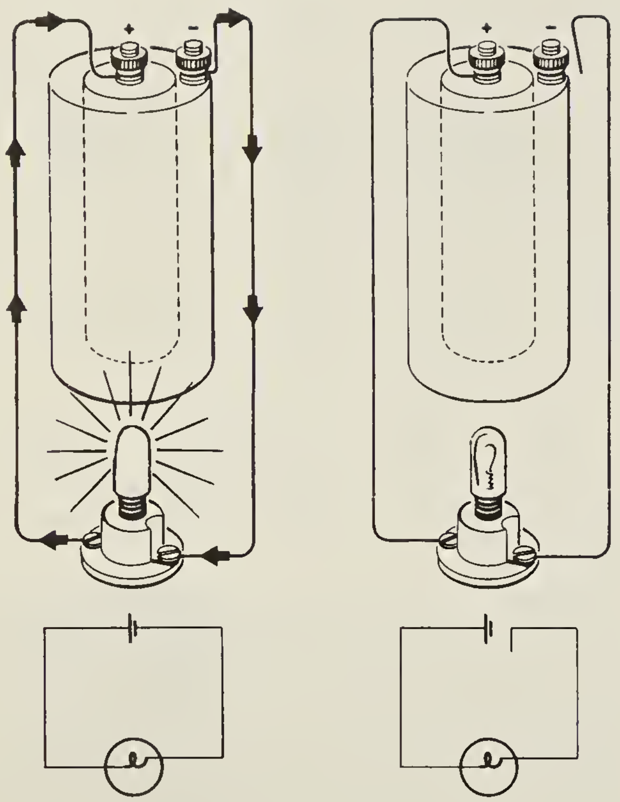


Figure 2-1. (A) Simple electric circuit (closed); (B) simple electric circuit (open).

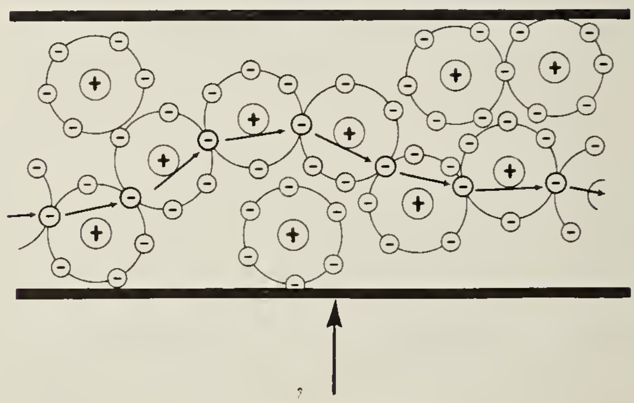


Figure 2-2. The electron flow through a conductor.

Current flow in the internal battery circuit is the simultaneous movement in opposite directions of positive hydrogen ions toward the positive terminal of the battery and negative ions toward the negative terminal. That is, current flows from the negative (−) terminal of the battery through the lamp to the positive (+) battery terminal, and continues by going through the battery from the positive (+) terminal to the negative (−) terminal. As long as this pathway is unbroken, it is a closed circuit and current will flow. However, if the path is broken at any point, it is an open circuit and no current flows. (See Fig. 2-1B.)

It should be remembered that any particular electron does not move from one end of a conductor to the other. The movement, rather, may be compared to a locomotive bumping a standing string of boxcars on a track. When the engine bumps one end of the string, each car progressively bumps the next. (Figure 2-2 represents a greatly magnified section of a conductor.) If a free electron from a source of energy is forced into an atom at one end, it tends to upset the balance between the electrons and protons of the atom. This forces another free electron from that atom to shift to an adjacent atom, thus upsetting its balance. This shifting or drifting of free electrons toward the source of energy at the other end of the conductor is called *dynamic electricity*, or current, which is electricity in motion. All of this is possible because free electrons are repelled out of a substance having a high negative charge (zinc electrode) and are attracted to another substance having fewer electrons, or a positive charge (copper electrode).

The greater the difference between the concentration of electrons, the greater will be the electromotive force. In everyday parlance, as we know, the term *voltage* is used to designate electromotive force. Incidentally, the *volt*, the unit of measure of emf, was established by Professor Volta while developing his primary cell (see p. 11). How he established his unit of pressure can be explained better after an explanation of the other factors pertaining to the flow of electrons in a circuit. Voltage can be measured with an instrument called a *voltmeter*.

Potential difference. If two substances having an equal concentration of free electrons are connected by a conductor, there will be no movement of electrons from one substance to the other, and the two substances are said to be at the same *potential.* If, however, one substance has a higher concentration of free electrons than the other, they are said to have a *potential difference* between them. Here again, the greater the difference between the concentration of free electrons in the electrodes, the greater will be the potential difference. Free electrons always move from a point of high potential toward one of lower potential, which means that they move from a negative electrode toward a positive electrode in an electric circuit. Using water again as an analogy, the potential difference in electricity can be compared with a tank of water on top of a high tower. The water in the tank has a higher pressure potential than the water in a bucket placed at the end of a pipe leading from the bottom of the tank.

While the terms *electromotive force*, or *voltage*, and *potential difference* are closely related and are often used interchangeably, there is a technical difference between them. In brief, *emf*, or *voltage*, is the pressure produced throughout an electric circuit, while *potential difference* indicates the ratio of electron potency or concentration between the electrodes of a battery or between certain components of other current-producing devices.

Quantity

Coulomb. Just as units of measure have been established to measure the quantity of liquids, so have units been established to measure the quantity of electricity. When dealing with large quantities of water, the term *gallon* is applied. We say that a gallon is 4 quarts, 8 pints, or 128 ounces. While the electron can be considered to be a quantity of electricity, it is too small to be used as a standard measure. A larger unit, comprising 6.3 billion billions of electrons, is called a *coulomb* (C) and is the standard electrical unit of quantity measure. The name is in honor of Charles Coulomb, a French physicist, who made investigations into magnetism and electricity.

Although the coulomb is a definite quantity of electrons which can be measured in a laboratory, it is of little concern to us from a practical standpoint. In other words, we do not measure coulombs directly in diagnosis procedures.

Rate of Flow

Coulombs alone can no more measure the strength of an electric current than the gallon alone can measure the strength of a waterfall. Both must be considered in their relation to time. If it were said that Niagara Falls spills 5 million gallons of water, it would mean very little unless the time required for this amount to spill is also given. If it took a year to spill this amount, it would not be much of a waterfall. However, it is known that it takes only an hour, and from this its strength can be determined. The rate of flow of electrons is measured in *amperes*.

Ampere. As defined in Chap. 1, the ampere (A) is the unit of measure of current strength. One ampere, as was noted in Chap. 1, equals one coulomb per second (or, stated in symbols, $1\ A = 1\ C/s$). This means that when 1 C passes a point in a circuit each second, the rate of flow is 1 A. Coulombs are quantity, amperes are rate of flow or strength of current. An ordinary light bulb may require $\frac{1}{2}$ A, while a 36-in searchlight may require 150 A. This shows that the searchlight is about 300 times as strong as the light bulb. This unit of measure was named in honor of André Ampere, a French scientist, and is measured by an ammeter (see p. 115).

Resistance

The last, but very important, factor in our understanding of electricity is the *resistance* to the flow of electrons encountered in a conductor. Most metals have a low resistance and are considered good conductors, because the molecules are loosely hung together and have many free electrons. Or in other words, the attraction between the electrons and the protons (or

nucleus) is weak, and the electrons can be readily pushed out. Copper is one of these metals, and is widely used in conducting electricity. Of course, all matter, including copper, presents a certain amount of resistance to the flow of current by attempting to retain its own electrons. In any circuit, the resistance of the conductor must be overcome by the force of the current. If the force is great or the resistance is small, strong current flows. On the other hand, if the force is small or the resistance is great, only a small amount of current will flow.

A comparison can be made between the resistance factors pertaining to water and those pertaining to electricity. There are four factors which determine the resistance to the flow of water through a pipe. They are (1) diameter of the pipe, (2) length of the pipe, (3) kind of pipe, and (4) velocity of flow.

The smaller the pipe, the longer the pipe, and the rougher the interior of the pipe, the more friction there is. Friction is resistance, and so the greater the friction, the smaller will be the volume of flow for a given time period.

Electric conductors. Electric conductors (wires) are the "pipes" of an electric circuit. The resistance of these wires is dependent on four factors. They are (1) diameter of the wire, (2) length of the wire, (3) kind of wire, and (4) temperature of the wire.

If the wire is long, or is small in diameter, the flow of current is less. Likewise, if the wire is of iron, the flow of current is less than it would be if copper were used. Temperature also affects the resistance of electric conductors to some extent. In most conductors (copper, aluminum, iron, etc.) the resistance increases with temperature. Carbon is an exception. In carbon the resistance decreases as temperature increases. Certain alloys of metals (manganin and constantan) have a resistance that does not change appreciably with temperature.

The relative resistance of several conductors of the same length and cross section is given in the following list, with silver as a standard of 1 and the remaining metals arranged in an order of ascending resistance:

Silver	1.0
Copper	1.08
Gold	1.4
Aluminum	1.8
Platinum	7.0
Lead	13.5

If the resistance of a conductor is increased by any one of the four factors, the current is decreased. From this it can be readily seen that if you wish to install wires from a source of power to a load, such as an electric range or a large condensing unit, the wires should be large enough to carry the load and should be of a low-resistance material such as copper. There is one exception to the temperature-resistance factor that is of particular interest to us from a practical standpoint. When certain substances such as oxides of manganese, nickel, and cobalt are mixed and formed into a solid, they form a semiconductor called a *varistor* or *thermistor*.

Thermistors are conductors whose resistance to the flow of electricity decreases as their temperature increases. In other words, at a low temperature, their resistance is so high that very little voltage and current can flow through them. As the temperature of the metal is increased, either by the current it passes or by externally applied heat, more current proportionately flows through it. Although the number of applications for thermistors is on the increase, there are only two important devices associated with home appliances and testing equipment in which they are used.

The current models of some ovens feature a meat-tender indicator which sounds a buzzer when the interior of a roast has reached a predetermined temperature. This is made possible because of a small thermistor in the tip of a sensing probe. When the probe is inserted in the roast, and the oven is turned on, the insulating effect of the meat keeps the tip relatively cool and the flow of current through the meat-tender circuit is held at a minimum. As the meat heats and the tip gradually increases in temperature, however, the flow of current increases, which moves the indicator on the

control panel of the range closer to the point at which a set of contacts closes to complete a buzzer circuit.

Another application of thermistors is in connection with a low-temperature test instrument. A small thermistor disk is located in the tip of the sensing bulb. The colder the temperature of the sensing bulb, the smaller will be the current flow through the meter circuit. The temperature tester is actually an electric meter which measures temperatures by sensing minute currents with a thermistor. The dial of the instrument is calibrated in degrees Fahrenheit.

Ohm. Just as the volt is a unit of measure for electromotive force and the ampere is a unit of measure for the rate of flow of electric current, so is the *ohm* (Ω) the unit of measure for the resistance of a conductor to the flow of electrons. The unit of resistance was developed by Georg S. Ohm, a German scientist. To establish the unit of measure, he used a column of mercury 106.3 cm in height and 1 mm^2 in cross section. 1 Ω is the resistance offered by this column of mercury to the flow of 1 A of current having an electromotive force of 1 V. The temperature of the mercury was 32°F. This column of mercury is comparable to 1,000 ft of No. 10 wire, which is $\frac{1}{10}$ in in diameter, or 2.4 ft of No. 36 wire, which is 0.005 in in diameter. Resistance is measured by an *ohmmeter*.

Conductance Electricity is a study that is frequently explained in terms of opposites. The term that is exactly the opposite of *resistance* is *conductance*. Conductance (G) is the ability of a material to pass electrons. The unit of conductance is the *mho*, which is ohm spelled backwards. Whereas the symbol used to represent resistance is the Greek letter omega (Ω), the symbol used to represent conductance is the Greek letter omega upside down (℧). The relationship that exists between the resistance and conductance is reciprocal. A reciprocal of a number is obtained by dividing the number into 1. In terms of resistance and conductance,

$$R = \frac{1}{G}$$

$$G = \frac{1}{R}$$

If the resistance of a material is known, dividing its value into 1 will give its conductance. Similarly, if the conductance is known, dividing its value into 1 will give its resistance.

ELECTRIC CIRCUITS

As previously stated, an electric circuit is a path or a group of interconnected paths capable of carrying electric currents. To make use of an electric current to do useful work, it must be passed through an electrically operated device. The device is referred to as the *load*. This load device is connected to a power source, which may be a battery or a generator, in such a way that the current leaves the power source, passes through the load which it operates (or in which it does useful work), and returns to the power source.

A simple electric circuit is illustrated. Current flows from the negative terminal of the generator or battery, via the top wire, through the switch and the load, and back via the bottom wire to the positive terminal of the generator or battery. The current continues to flow in this manner as long as the connections are intact and the generator or battery is able to maintain the necessary electromotive force (emf), or voltage. As previously stated, the emf is the electric pressure that drives the current through the circuit. The wires leading to and from the load form a conducting path for the current, or flow of electrons. If the path is broken at any point, the current will stop flowing in the entire circuit. The circuit is then said to be *open*. If the path is not broken at any point, the circuit is said to be *closed*. The switch placed in the top wire lead is simply a device for opening and closing the circuit at will.

A circuit is any route which the current must travel from the power source to the load and back to the power source. It may be a single

path or it may be a group of interconnected paths. But since we have established that electric circuits are the electron carriers of an electric system, and since they can be quite complex, it is important that several fundamental facts be thoroughly understood. However, no matter how complex any particular circuit becomes, it is one of three general types. The three types of circuits are the *series*, the *parallel*, and the *series-parallel*.

The series is a one-path circuit and can be recognized in two ways. It will never have more than one conductor connected to one terminal, and there will be only one path from source to load and back to source.

In a parallel circuit there are two or more paths between the terminals of the source of current.

A series-parallel circuit, as the name implies, is a combination of both.

Every electric load is designed to have a specific resistance and to operate at a certain voltage. The resistance controls the amount of current at the rated voltage.

Schematic diagrams. A *schematic* is a diagram in which symbols are used for the various components instead of pictures. These symbols are used in an effort to make the diagrams easier to draw and easier to understand. In this respect, schematic symbols aid the service technician in the same way that shorthand aids the stenographer. The schematic symbols used in these books conform to the graphic symbols and electronic diagrams approved by the American National Standards Institute (ANSI). A complete glossary of symbols is given in Appendix E of this book.

In studies of electricity and electronics many circuits are analyzed which consist mainly of specially designed resistive components. As previously stated, these components are called resistors. Throughout the remaining analysis of the basic circuit, the resistive component will be a physical resistor. However, the resistive component could be any of several electrical devices.

A closed loop of wire (conductor) is not necessarily a circuit. A source of voltage must be included to make it an electric circuit. In any electric circuit where electrons move around a closed loop, current, voltage, and resistance are present. The physical pathway for current flow is actually the circuit. Its resistance controls the amount of current flow around the circuit. By knowing any two of the three quantities, such as voltage and current, the third (resistance) may be determined. This is done mathematically by the use of Ohm's law.

Ohm's law. Ohm did more than experiment with resistance; he connected his own discoveries with those of Volta and Ampere, and in 1827 he formulated the all-important *Ohm's law*, upon which is based all electrical measurement. Ohm's law states that *the current in an electric circuit is directly proportional to the applied voltage and inversely proportional to the circuit resistance.* Ohm's law may be expressed as an equation:

$$I = \frac{E}{R}$$

where I = current (flow), in amperes
E = voltage (pressure), in volts
R = resistance, in ohms

If any two of the quantities in an equation are known, the third may be easily found. For example, the schematic diagram in Fig. 2-3B shows a circuit containing a resistance of 3 Ω and a source voltage of 12 V. How much current flows in the circuit?

Given: $E = 12\ \text{V}$
$R = 3\ \Omega$
$I = ?$

Solution: $I = \frac{E}{R}$

$I = \frac{12}{3}$

$I = 4\ \text{A}$

To observe the effect of source voltage on circuit current, the above problem will be solved again using double the previous source voltage.

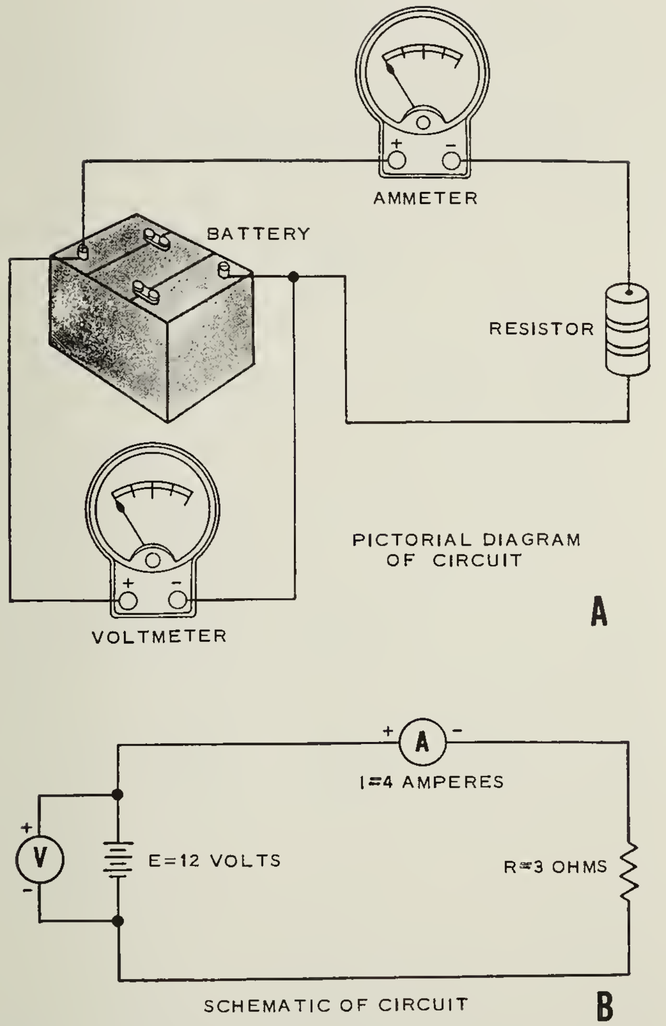


Figure 2-3. A simple circuit: (A) semi-pictorial diagram; (B) schematic diagram.

Given: $E = 24$ V

$R = 3\ \Omega$

$I = ?$

Solution: $I = \dfrac{E}{R}$

$I = \dfrac{24}{3}$

$I = 8$ A

Notice that as the source voltage doubles, the circuit current also doubles. That is, circuit current is directly proportional to applied voltage and will change by the same factor that the voltage changes. To verify the statement that

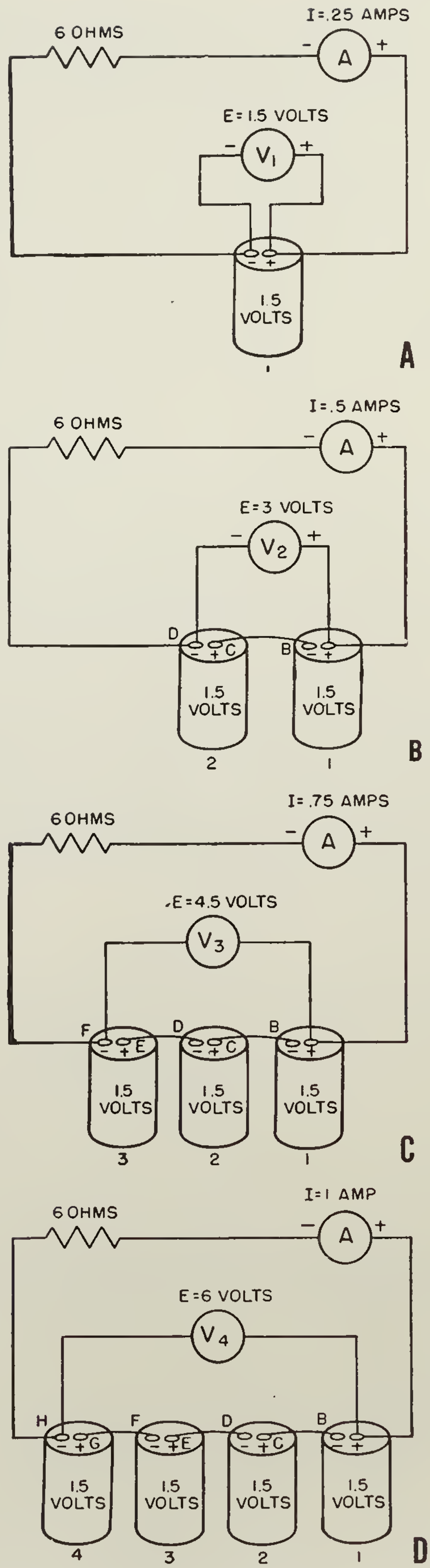


Figure 2-4. Effect of changing voltage.

current is inversely proportional to resistance, assume the resistor in the schematic diagram (Fig. 2-3B) to have a value of 6 Ω.

Given: $E = 12$ V

$R = 6\ \Omega$

$I = ?$

Solution:

$$I = \frac{E}{R}$$

$$I = \frac{12}{6}$$

$$I = 2 \text{ A}$$

Comparing this current of 2 A for the 6-Ω resistor to the 4 A of current obtained with the 3-Ω resistor shows that doubling the resistance will reduce the current to one-half the original value. Circuit current is inversely proportional to the circuit resistance.

In many circuit applications current is known and either the voltage or the resistance will be the unknown quantity. To solve a problem in which current and resistance are known, the basic formula for Ohm's law must be transposed to solve for E as follows:

Basic equation: $I = \dfrac{E}{R}$

Multiply both sides of the equation by R:

$$IR = \frac{E}{\cancel{R}}\cancel{R}$$

$$IR = E$$

$$E = IR$$

To transpose the basic formula when resistance is unknown:

Basic equation: $I = \dfrac{E}{R}$

Multiply both sides of the equation by R:

$$IR = \frac{E}{\cancel{R}}\cancel{R}$$

$$IR = E$$

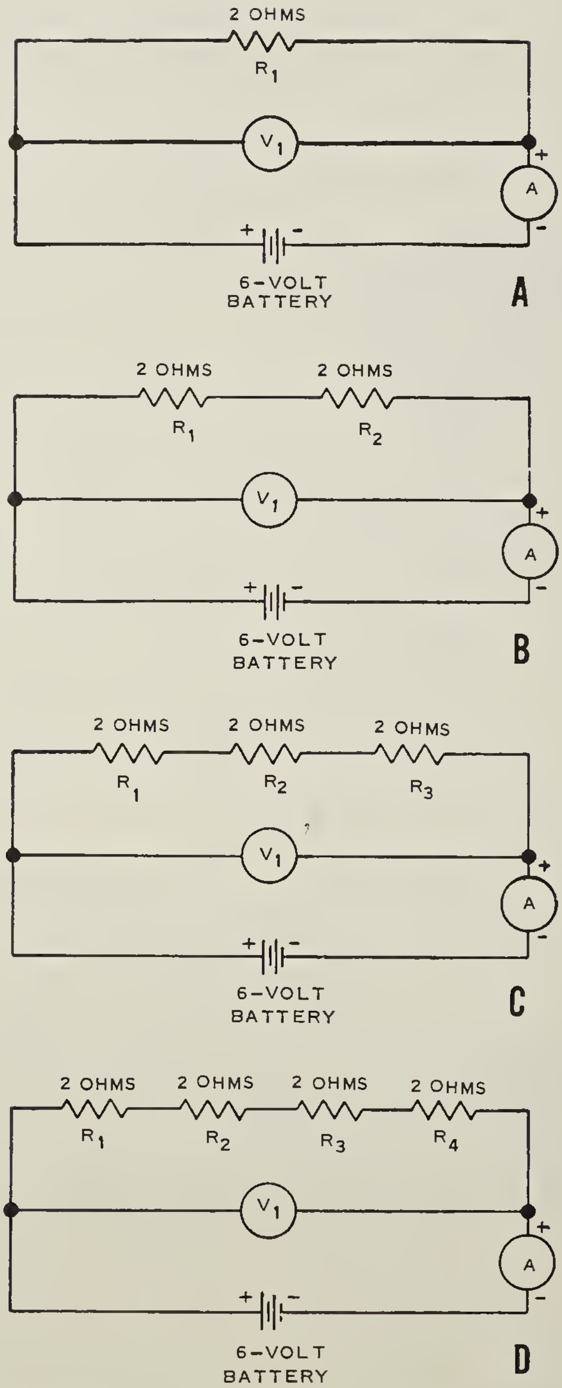


Figure 2-5. Effect of changing resistance.

Divide both sides of the equation by I:

$$\frac{\cancel{I}R}{\cancel{I}} = \frac{E}{I}$$

$$R = \frac{E}{I}$$

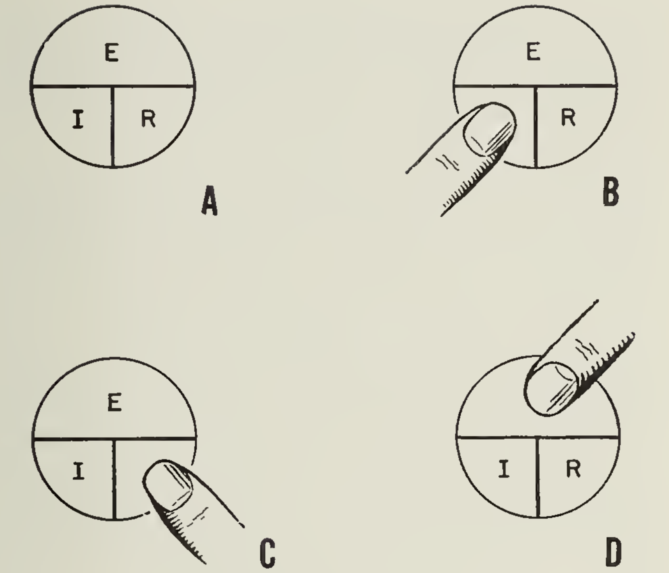


Figure 2-6. Memory aid for learning Ohm's law. Part A of this figure shows a circle with the three symbols arranged in separate spaces. If any one of the symbols is covered, the arrangement of the other two symbols forms the right-hand side of the formula for determining the value of the covered symbol. Thus, (B) if a finger is placed over the I, E/R remains, and indicates that $I = E/R$; (C) if R is covered, E/I remains, and indicates that $R = E/I$; and (D) if E is covered, IR remains, and indicates that $E = IR$.

Rise or fall of potential, voltage drops. It is important to understand what is meant by a rise of voltage, a fall of voltage, and a voltage drop. In Fig. 2-7A the battery voltage, or potential difference between the battery terminals, is 200 V, as indicated by voltmeter V_1. By Ohm's law, the current through resistor A-B is

$$I = E/R = 200/100 = 2 \text{ A}$$

Also by Ohm's law, the voltage across the resistor is

$$E = IR = 2 \times 100 = 200 \text{ V}$$

This voltage is, of course, the same as the battery voltage, for it is assumed that the resistance of the connecting leads is negligible.

The negative terminal of the battery (Fig. 2-7) is being used as the reference or zero point for measuring the potentials of all other points in the circuit. Thus, point A is the point of highest potential (200 V), positive with respect to the point of lowest potential (zero) at B. In Fig. 2-7B, the 100-Ω resistor of Fig. 2-7A is replaced by four 25-Ω resistors R_1, R_2, R_3, and R_4 which are connected between points A-B, B-C, C-D, and D-E, respectively. Measurements with voltmeters (V_1, V_2, V_3, and V_4) show that the potentials of E, D, C, B, and A (taken in this order) are 0, 50, 100, 150, and 200 V positive. This shows that there is an increase or rise of voltage from E towards A. If the resistance is distributed uniformly along the length E-A, the voltage rise will also be uniform. This is indicated by the fact that the rise across each section in Fig. 2-7B is 50 V.

Suppose that, in Fig. 2-7B, the potential at A is first measured and that the potential at B is then measured. Obviously, the potential at B is lower than the potential at A, and we say that there is a fall or drop of potential from A to B. Apparently, whether there is a potential rise or fall between two points depends entirely on our point of view. For example, in Fig. 2-7B it is equally correct to say that there is a voltage rise from B to A, or a voltage fall from A to B.

In practical work, as previously mentioned, our interest usually is centered on voltages and currents in operating circuits. A voltmeter

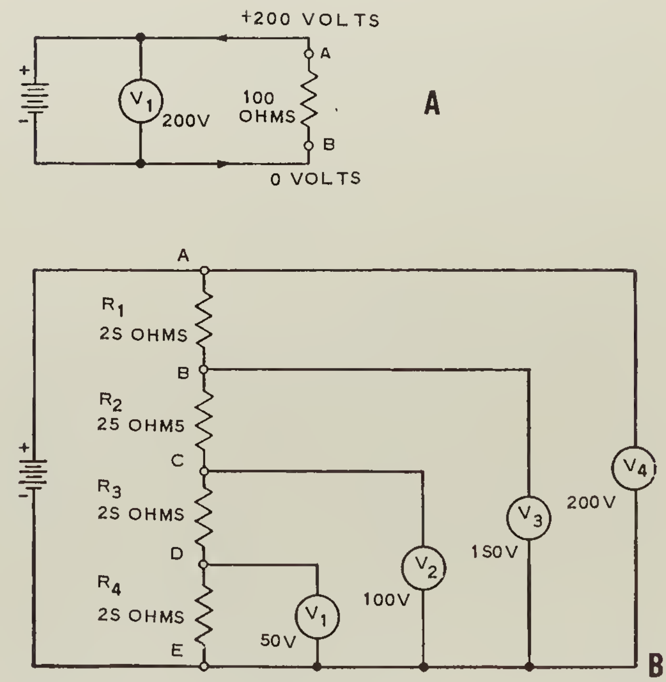


Figure 2-7. Rise and fall of potential.

always indicates the potential difference between the two points to which it is connected. Thus, if a voltmeter is successively connected across *A-B*, *B-C*, *C-D*, and *D-E*, it will, in each instance, show a potential difference of 50 V. The voltage across a portion of a circuit is called the voltage drop across that portion of the circuit. Consider points *D-E*. The resistance between these points is 25 Ω and the current is 2 A. From Ohm's law, $E = IR$ and, in this instance,

$$E_{C\text{-}D} = 2 \times 25 = 50 \text{ V}$$

Similarly considering points *C-E*, the resistance is 25 Ω (*C-D*) plus 25 Ω (*D-E*), or 50 Ω, and the current is 2 A. Then,

$$E_{C\text{-}E} = 2 \times 50 = 100 \text{ V}$$

Voltage drops are also called *IR drops*. The meaning of *IR* drop is apparent when it is remembered that the voltage drop *E* across a resistance is calculated from the Ohm's law formula, $E = IR$.

In practical work the term *voltage* drop is usually used to indicate the potential difference required to produce the current through the two points being considered. As explained previously, the sum of the voltage drops around the entire circuit is equal to the emf. When the entire circuit is not considered, the sum of the voltage drops in the external circuit will equal the potential difference between the terminals of the source with the external circuit connected. Thus,

$$E_{R_1} + E_{R_2} + E_{R_3} + E_{R_4} = E_{\text{battery}}$$

and $50 + 50 + 50 + 50 = 200$ V.

Series DC Circuits

As previously mentioned, an electric circuit is a complete path through which electrons can flow from the negative terminal of the voltage source, through the connecting wires or conductors, through the load or loads, and back to the positive terminal of the voltage source. A circuit is thus made up of a voltage source, the necessary connecting conductors, and the effective load.

If the circuit is arranged so that the electrons have only one possible path, the circuit is called a series circuit. Therefore, a series circuit is defined as a circuit that contains only one path for current flow.

Resistance in series circuits. As shown in Fig. 2-7, a 100-Ω resistor (A) can be replaced by four 25-Ω resistors in series (B). Similarly, a 10-Ω resistor and two 20-Ω resistors in series can be replaced by a single 50-Ω resistor. This illustrates a law for resistances in series: *The total resistance is the sum of the individual resistances.* In Fig. 2-7B, the four resistances R_1, R_2, R_3, and R_4 are in series. If R_T represents the total resistance from *A* to *E*, then

$$R_T = R_1 + R_2 + R_3 + R_4$$

If R_T is the total resistance and *E* is the applied (in this instance) battery voltage, the current *I* can be determined from Ohm's law:

$$I = \frac{E}{R_T}$$

Current in series circuits. In Fig. 2-8, current flow is from the negative terminal of the battery through ammeter *A*, resistance R_1, ammeter A_1, resistance R_2, ammeter A_2, resistance R_3, ammeter A_3, and through the battery from the

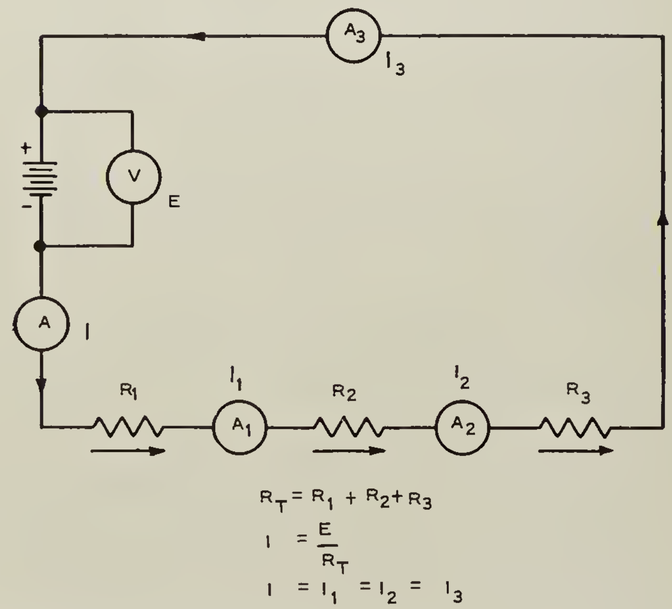


Figure 2-8. The same current flows through every part of a series circuit.

positive to the negative terminal. Obviously, there is but one path for the current, and so the same current must be indicated by ammeters A, A_1, A_2, and A_3. This illustrates a law for series circuits: *In a series circuit the current is everywhere the same; or, the same current flows in each part of the circuit.* Thus, in the schematic,

$$I = I_1 = I_2 = I_3$$

Voltage in series circuits. Energy is expended in the resistance of an electric circuit; that is, in a resistance electric energy is converted to heat energy. In Fig. 2-9, a 24-V battery is connected to three resistances in series: R_1 of 3 Ω, R_2 of 6 Ω, and R_3 of 3 Ω. The voltage required to produce the current in each of these resistances is called the *voltage drop* across each resistor. These voltage drops may be measured by connecting a voltmeter across each resistor. The voltage drops may also be calculated from Ohm's law. The total resistance R_T is the sum of the individual resistances:

$$R_T = R_1 + R_2 + R_3 = 12\,\Omega$$

E is given as 24 V; therefore,

$$I = \frac{E}{R_T} = \tfrac{24}{12} = 2\text{ A}$$

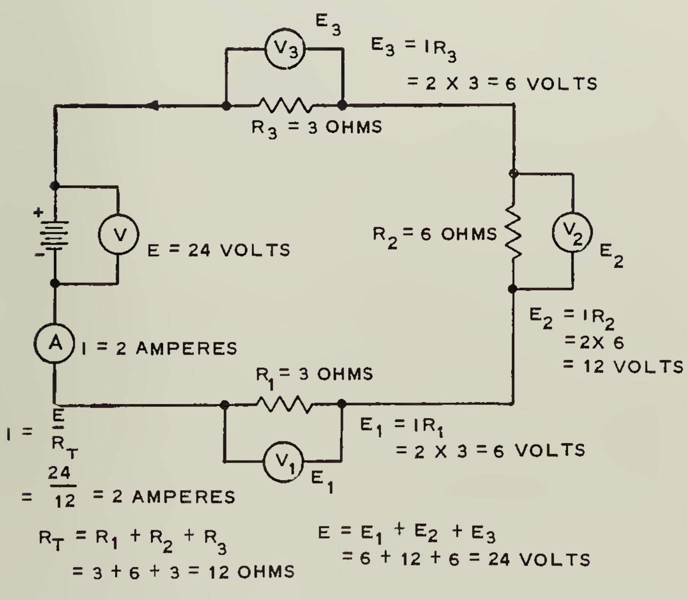


Figure 2-9. In a series circuit, R_t equals the sum of the individual resistances.

Applying Ohm's law to each part of the circuit,

$$E_1 = R_1 \times I = 3 \times 2 = 6\text{ V (across } R_1)$$
$$E_2 = R_2 \times I = 6 \times 2 = 12\text{ V (across } R_2)$$
$$E_3 = R_3 \times I = 3 \times 2 = 6\text{ V (across } R_3)$$

On adding the individual drops, we find that their sum is equal to the battery voltage:

$$E = E_1 + E_2 + E_3$$
$$E = 6 + 12 + 6 = 24\text{ V}$$

This illustrates a law for series circuits: *In a series circuit, the sum of the individual voltage drops is equal to the applied voltage.*

A common example of this law is a string of Christmas tree lights of the series type. The rated voltage of each bulb is approximately 15 V. When the bulbs are connected in a series of eight, the combined voltage totals approximately that of the source of 115 to 120 V.

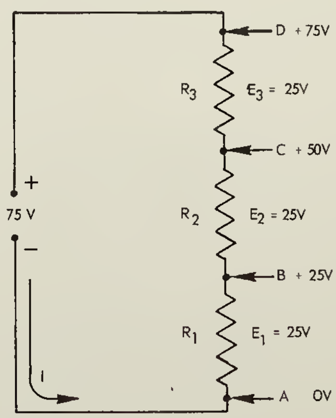


Figure 2-10. Reference points in a series circuit.

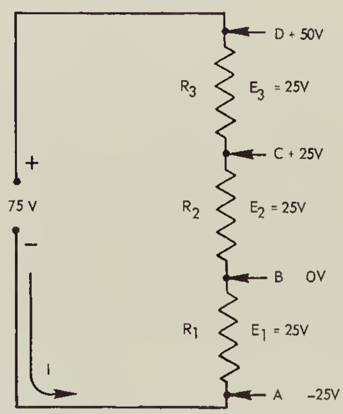


Figure 2-11. Determining potentials with respect to a reference point.

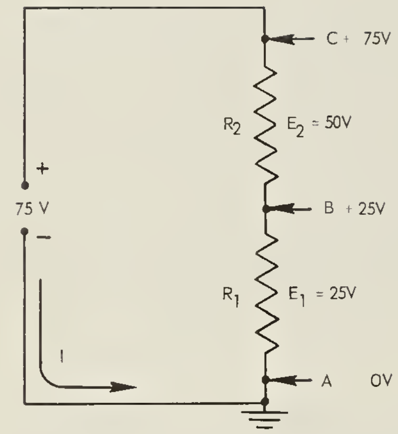


Figure 2-12. Use of a ground symbol.

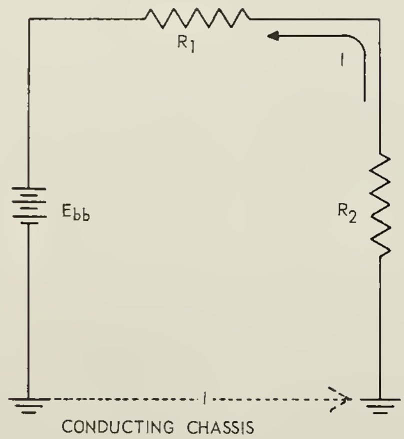


Figure 2-13. Ground used as a conductor.

Open and shorted series circuits. A circuit is said to be *open* when a break exists in a complete conducting pathway. Although an open occurs any time a switch is thrown to de-energize a circuit, an open may also develop accidentally due to abnormal circuit conditions. To restore a circuit to proper operation, the open must be located and its cause determined.

Sometimes an open can be located visually by a close inspection of the circuit components. Defective components, such as burned-out resistors and fuses, can usually be discovered by this method. Others, such as a break in wire covered by insulation, or the melted element of an enclosed fuse, are not visible to the eye. Under such conditions, the understanding of an open's effect on circuit conditions enables a technician to make use of a voltmeter or an ohmmeter to locate the open component.

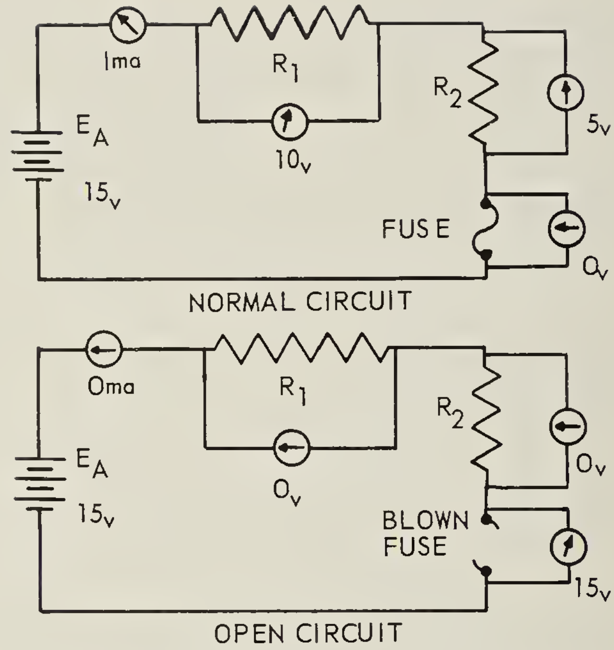


Figure 2-14. Normal and open-circuit conditions.

In Fig. 2-14, the series circuit consists of two resistors and a fuse. Notice the effects on circuit conditions when the fuse opens. Current ceases to flow; therefore, there is no longer a voltage drop across the resistors. Each end of the open conducting path becomes an extension of the battery terminals, and the voltage measured across the open is equal to the applied voltage.

An open circuit can also be located with an ohmmeter. However, when using an ohmmeter to check a circuit, it is important to first de-energize the circuit. The reason for this is that an ohmmeter has its own power source and would be damaged if connected to an energized circuit (see page 153).

The ohmmeter used to check a series circuit would indicate the ohmic value of each resistance it is connected across. The open circuit, because of its almost infinite resistance, would cause no deflection on the ohmmeter, as indicated by the illustration, Fig. 2-15.

A *short circuit* is an accidental path of low resistance which passes an abnormal amount of current. A short circuit exists whenever the resistance of the circuit or the resistance of a part of a circuit drops in value to almost 0 Ω. A

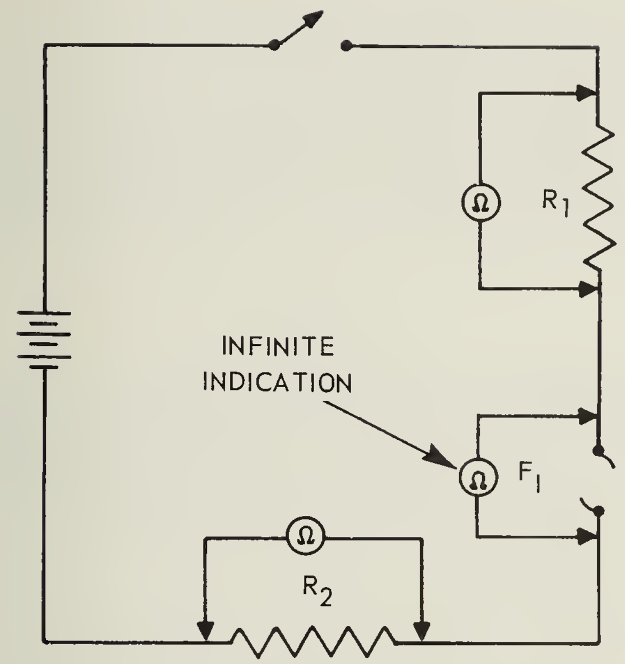


Figure 2-15. Ohmmeter readings in a series circuit.

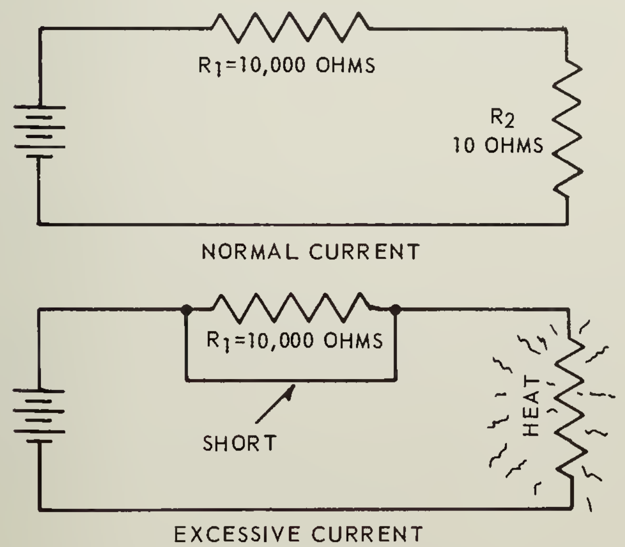


Figure 2-16. Normal and short-circuit conditions.

short often occurs as a result of improper wiring or broken insulation.

In Fig. 2-16, a short is caused by improper wiring. Note the effect on current flow. Since the 10,000-Ω resistor has in effect been replaced with a piece of wire, practically all the current flows through the short and very little current flows through the resistor. Electrons flow through the short, a path of almost zero resistance and complete the circuit by passing through the 10-Ω resistor and the battery. The amount of current flow increases greatly because its resistive path has decreased from 10,010 Ω to 10 Ω. Due to the excessive current through the 10-Ω resistor, the increased heat generated in the resistor will destroy it.

Parallel DC Circuits

As already mentioned, a parallel circuit is defined as one having more than one current path connected to a common voltage source. Parallel circuits, therefore, must contain two or more load resistances which are not connected in series. A comparison of a basic series and parallel circuits is shown in Fig. 2-17.

In the parallel circuit (Fig. 2-17B), if we start at the voltage source and trace counterclockwise around the circuit, we can identify two complete and separate paths in which current can flow. One path is traced from the source through resistance R_1 and back to the source; the other is from the source through resistance R_2 and back to the source.

Voltage in parallel circuits. You have seen that the source voltage in a series circuit divides proportionately across each resistor in the circuit. In a parallel circuit, the same voltage is present across all the resistors of a parallel group. This voltage is equal to the applied voltage. For example, Fig. 2-18A is the schematic diagram of a circuit in which the negative terminal of a 6-V battery is connected to point *B*, the positive terminal is connected to point *A*, and

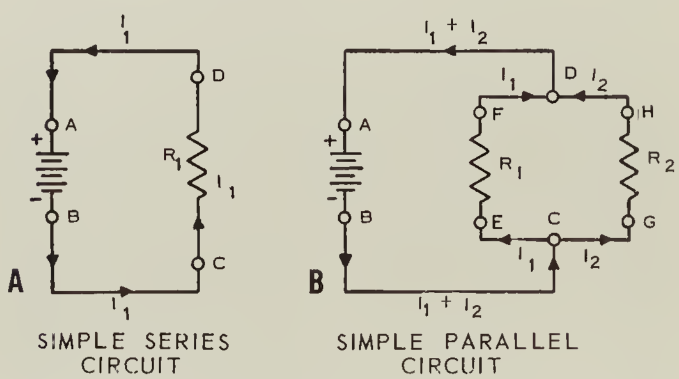


Figure 2-17. A comparison of simple series and parallel circuits.

resistors R_1, R_2, and R_3 are connected in parallel between points A and B. Since A and B are directly connected to the battery terminals, the potential difference between A and B is 6 V. Each resistor is also connected between points A and B, and the same voltage is applied to each resistor. Thus, voltmeters V_1, V_2, and V_3 indicate the same voltage. This illustrates how voltages react in a parallel circuit; *in a parallel circuit, the same voltage is applied to each branch.* Thus E, E_1, E_2, and E_3 are the same voltage.

Current in parallel circuits. As we know, current in a circuit is inversely proportional to the circuit resistance. This fact, obtained from Ohm's law, establishes the relationship upon which the following discussion is developed. A single current flows in a series circuit. The value of this current is determined in part by the total resistance of the circuit. However, the source current in a parallel circuit divides among the available paths in relation to the value of the resistors in the circuit. Ohm's law remains unchanged. For a given voltage, current varies inversely with resistance.

If Fig. 2-18A is rearranged so that only R_1 is in the circuit (Fig. 2-18B), we have a simple series circuit consisting of the 6-V battery and R_1. From Ohm's law the current I_1 through R_1 is

$$I_1 = \frac{E}{R} = \tfrac{6}{3} = 2 \text{ A}$$

This current is indicated by ammeters A and A_1. When the 2-Ω resistor R_2 is placed in parallel with R_1 (Fig. 2-18C), the same voltage is applied to both resistors. (This assumes that the battery voltage remains constant at 6 V.) The current I_2 through R_2 is

$$I_2 = \frac{E}{R} = \tfrac{6}{2} = 3 \text{ A}$$

This 3-A current is indicated on ammeter A_2. The current I_T from the battery is the sum of the two currents, $I_1 + I_2$, or

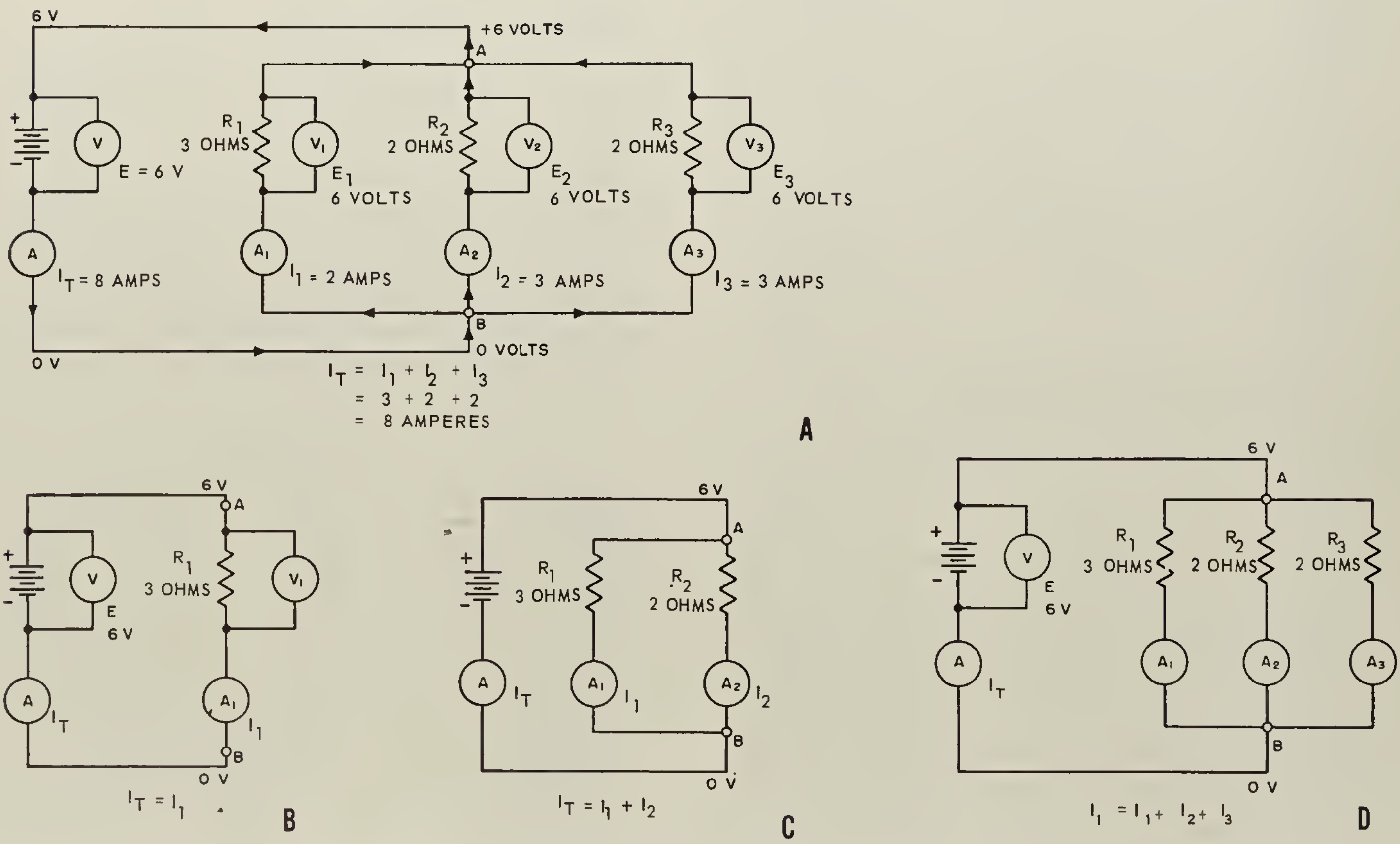


Figure 2-18. Voltage and current distribution in simple parallel circuits.

$$I_T = 2 + 3 = 5 \text{ A}$$

When the 2-Ω resistor R_3 is connected in parallel with R_1 and R_2, as shown in Fig. 2-18D, the same 6 V is applied to R_3. The current I_3 through R_3 is

$$I_3 = \frac{E}{R} = \tfrac{6}{2} = 3 \text{ A}$$

This 3-A current is indicated by ammeter A_3. The total current from the battery is thus increased by 3 A and now is

$$I_T = I_1 + I_2 + I_3 = 2 + 3 + 3 = 8 \text{ A}$$

This 8-A current is indicated on ammeter A. From these results, a rule for current in parallel circuits may be stated: *The total current in a parallel circuit is equal to the sum of the currents in the individual branches.* Note that the current from the negative terminal of the battery divides to follow three paths from point B (Fig. 2-18A), recombines at point A, and returns to the positive terminal of the battery. The current that returns to the battery flows through the battery and is exactly equal to the current that leaves the battery. The current through any branch may be computed from Ohm's law, $I = E/R$, and depends on the amount of resistance in the branch.

Resistance in parallel circuits. The total or effective resistance of the circuit (Fig. 2-18A) may be computed from the Ohm's law formula $R = E/I$. Since the applied voltage E is 6 V and the total current I_T is 8 A,

$$R_T = \frac{E}{I_T} = \tfrac{6}{8} = 0.75\ \Omega$$

where R_T is the effective resistance of the three resistors R_1, R_2, and R_3 in parallel; I_T is the total current from the battery. Note that the effective resistance of R_1, R_2, and R_3 is only 0.75 Ω, considerably less than the resistance of any one of the resistances. The rule for resistances in parallel may be stated as follows: *The effective resistance of a parallel circuit may be determined by dividing the applied voltage by the total current; it is always less than the resistance of the lowest resistance in the circuit.*

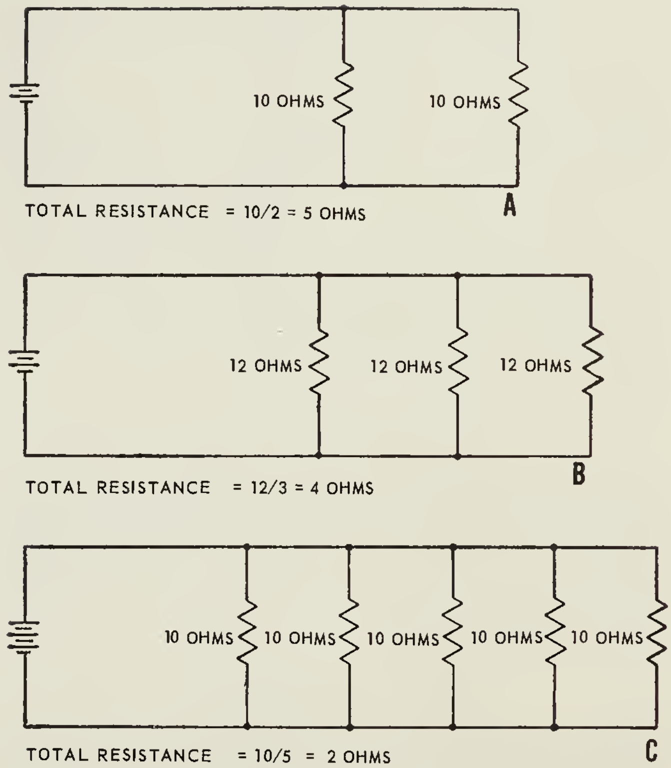


Figure 2-19. Equal resistances in parallel.

As can be seen, the Ohm's law formula $R = E/I$ is satisfactory for finding the effective resistance when the voltage E and the total current I_T are known. However, it is often necessary to determine R when neither the voltage nor the current is known.

The simplest parallel arrangement consists of equal resistances in parallel. To obtain the effective resistance of such a combination, it is necessary only to divide the resistance of one resistor by the number of resistances. Thus, in Fig. 2-19A two 10-Ω resistors are connected in parallel, and the effective resistance is 10 divided by 2, or 5 Ω. With three 12-Ω resistors in parallel (Fig. 2-19B), the effective resistance is $\frac{12}{3}$, or 4 Ω. With five 10-Ω resistors in parallel (Fig. 2-19C), the effective resistance is $\frac{10}{5}$, or 2 Ω. This method for determining the effective resistance is called the *like method* because all the resistances must be equal.

In Fig. 2-20, two unequal resistances, A of 12 Ω and B of 4 Ω, are connected in parallel across a 24-V battery. Obviously, the rule for like

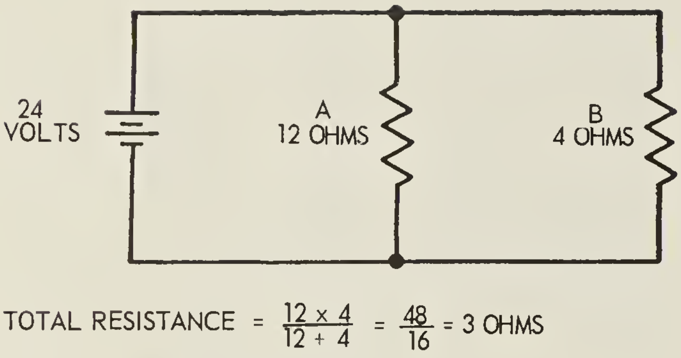


Figure 2-20. Product/sum method.

resistances cannot be applied. Since the same voltage is applied to each branch, the current through any branch is a function of the resistance in that branch. In this example, the current through resistor A is

$$I_A = \frac{E}{R_A} = \frac{24}{12} = 2\text{ A}$$

The current through resistor B is

$$I_B = \frac{E}{R_B} = \frac{24}{4} = 6\text{ A}$$

The total current I_T is

$$I_T = I_A + I_B = 2 + 6 = 8\text{ A}$$

The effective resistance of the circuit can be determined from the Ohm's law formula $R = E/I$.

$$R_T = \frac{E}{I_T} = \frac{24}{8} = 3\ \Omega$$

When the applied voltage is *not* known, *assume* any convenient voltage. For example, *assume* that a voltage of 6 V is applied to the parallel resistors A and B. The current through R will be

$$I_A = \frac{E}{R_A} = \frac{6}{12} = 0.5\text{ A}$$

The current through R_B will be

$$I_B = \frac{E}{R_B} = \frac{6}{4} = 1.5\text{ A}$$

The total current I_T will be

$$I_T = I_A = 0.5 + 1.5 = 2\text{ A}$$

The effective resistance can now be calculated:

$$R = \frac{E}{I_T} = \frac{6}{2} = 3\ \Omega$$

When only two parallel resistances are involved, another method, called the *product over the sum* (*product/sum*) *method*, may be the simplest to use. The rule for this method may be stated as follows: *The effective resistance of two resistances in parallel is equal to their product divided by their sum.* Applying this rule to the circuit just described,

$$R = \frac{\text{product}}{\text{sum}} = \frac{12 \times 4}{12 + 4} = \frac{48}{16} = 3\ \Omega$$

Notice that this result agrees with that obtained when an applied (or assumed) voltage is divided by the total current. However, only resistance values are used in this computation. (This method can, of course, be applied to two resistances of equal value.)

The product/sum method may be used to solve problems involving more than two resistances in parallel. To do this, first determine the effective resistance of any two of the parallel resistors, then combine the result of this calculation with any one of the remaining resistances. Continue the process of combining the calculated resistance with one of the remaining resistances until all the resistances have been included in the calculations. For example, Fig. 2-21 shows a circuit with three unequal resistances connected in parallel. The problem is to find the effective resistance. In other words, what is the resistance of a single resistor which offers the same opposition to current as the parallel combination? Apply the product/sum rule to resistors B and C, and call the resultant resistance R_D,

$$R_D = \frac{\text{product}}{\text{sum}} = \frac{B \times C}{B + C}$$

$$R_D = \frac{6 \times 3}{6 + 3} = \frac{18}{9} = 2\ \Omega$$

Since R_D is the effective resistance of B and C in parallel, R_D may now be substituted for B and C, as indicated in the schematic drawing. Applying the product/sum method to A and D,

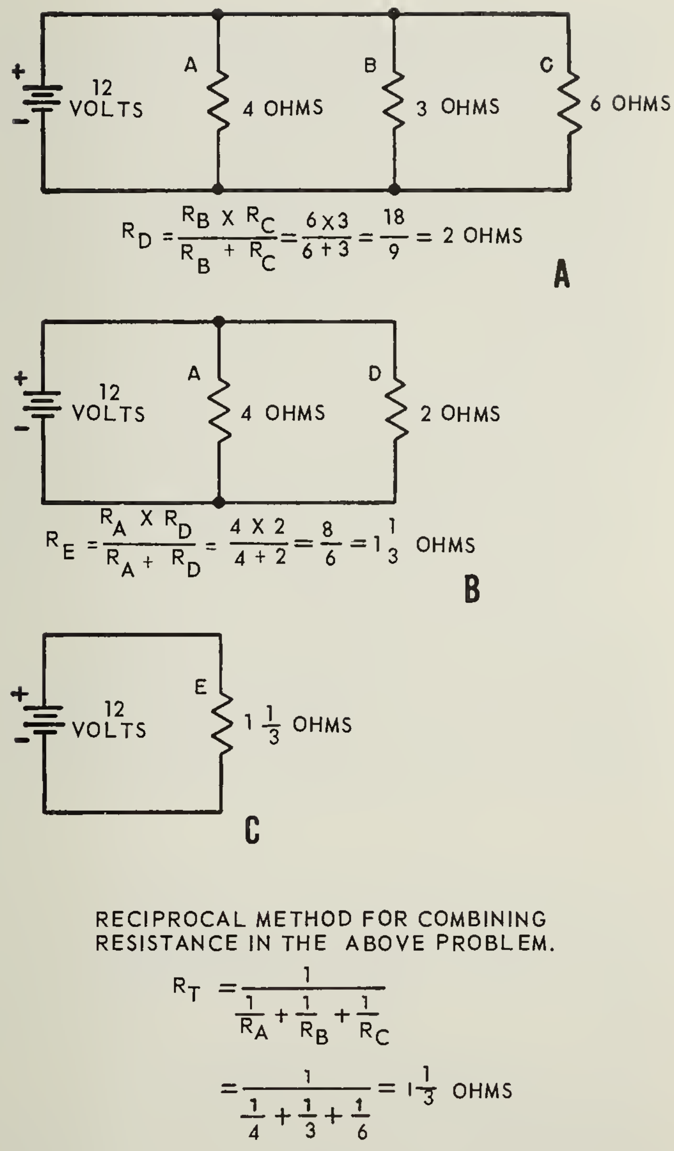


Figure 2-21. Product/sum and reciprocal methods.

and calling the result R_E,

$$R_E = \frac{4 \times 2}{4 + 2} = \tfrac{8}{6} = 1\tfrac{1}{3}\,\Omega$$

A single resistance R_E of $1\frac{1}{3}\,\Omega$ can be substituted for A, B, and C (Fig. 2-21A) as shown in Fig. 2-21C; that is, the effective resistance of A, B, and C in parallel is $1\frac{1}{3}\,\Omega$.

The product/sum method can be used only for two resistances at a time. If a circuit contains three or more resistances, the product/sum method of solution becomes long and tedious. The *reciprocal method* may be more conveniently used to determine the effective resistance of a number of parallel resistances. Stated as a rule: *The effective resistance of parallel resistances is equal to the reciprocal of the sum of the reciprocals of the individual resistances.* The reciprocal of a number is 1 divided by the number. Thus, the reciprocal of 2 is $\frac{1}{2}$ and the reciprocal of $\frac{1}{2}$ is 2; the reciprocal of 5 is $\frac{1}{5}$ and the reciprocal of $\frac{1}{5}$ is 5; and so on. The reciprocal method is stated by the following formula:

$$R = \frac{1}{1/R_1 + 1/R_2 + 1/R_3 + \cdots}$$

where R is the effective resistance and R_1, R_2, R_3, and so on, the parallel resistances. Substituting the values of A, B, and C (Fig. 2-21A) in the formula,

$$R = \frac{1}{\frac{1}{4} + \frac{1}{3} + \frac{1}{6}}$$

and $$R = \frac{1}{\frac{3}{12} + \frac{4}{12} + \frac{2}{12}} = \frac{1}{\frac{9}{12}} \text{ (adding fractions)}$$

Then $$R = 1 \times \tfrac{12}{9} = 1\tfrac{1}{3}\,\Omega \text{ (dividing 1 by } \tfrac{9}{12}\text{)}$$

This result is the same as that obtained by using the product/sum method. You should be familiar with all these methods for determining the effective resistance of resistances in parallel. If necessary, one method may be used to prove results obtained with another. Remember, too, that the effective resistance is *always* lower than the resistance of the lowest individual resistance in the circuit.

Open and shorted parallel circuits. In comparing the effects of an open in series and parallel circuits, the major difference to be noted is that an open in a parallel circuit would not necessarily disable the entire circuit; i.e., the current flow would not be reduced to zero unless the open condition existed at some point electrically common to all other parts of the circuit.

A short circuit in a parallel network has an effect similar to a short in a series circuit. In general, the short will cause an increase in current and the possibility of component damage regardless of the type of circuit involved.

Opens and shorts alike, if occurring in a branch circuit of a parallel network, will result in an

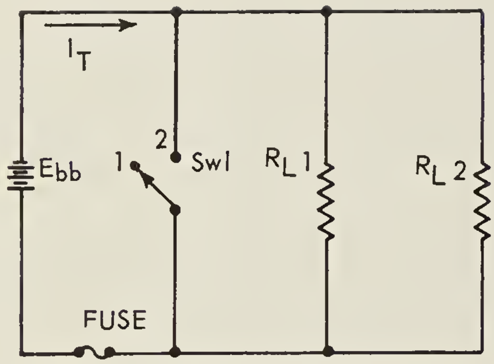


Figure 2-22. Example of a circuit protected from shorts by a fuse.

overall change in the equivalent resistance. This can cause undesirable effects in other parts of the circuit because of the corresponding change in the total current flow.

To prevent damage to equipment due to a short circuit, a fuse or overload relay is normally placed in the circuit in series with the more sensitive components or in series with the source. The effect of a short circuit occurring in a fused network is shown in Fig. 2-22 and is explained as follows: With the switch in position 1 (as shown), a value of current flows that does not exceed the rated current capacity of the fuse. If the switch is thrown to position 2, the straight-wire conductor will be in parallel with the load resistors. The equivalent resistance of the straight wire and the resistors, all connected in parallel, will be less than the resistance of the straight wire. This follows from the fact that the total resistance of a parallel circuit is always less than the smallest resistance in the branch. Since a complete path still exists to permit current flow, and the equivalent resistance is effectively zero, the current will rise rapidly until the current capacity of the fuse is reached. The fuse will then open the circuit causing the current to stop flowing. A short usually causes components to fail in a circuit which is not properly fused or otherwise protected. The failure may take the form of a burned-out resistor, a damaged source, or a fire in the circuit components and wiring.

Series-Parallel DC Circuits

Many circuits are neither simple series nor simple parallel, but a combination of both. While this may seem to present a fairly complex situation, it can be readily analyzed by distinguishing one type from the other and applying the correct laws for each type. For example, Fig. 2-23A in the diagram here is a schematic of a simple series-parallel circuit. This circuit is solved by applying the rules for simple series and simple parallel circuits. In such circuits we are concerned with:

1. The applied or source voltage and the voltage drops across each part of the circuit
2. The total current from the source and the current in each part of the circuit
3. The effective resistance and the resistance of each part of the circuit

In Fig. 2-23A, a 10-V battery is connected to a 5-Ω resistor, R_A, in series with two parallel resistors, R_B and R_C; Fig. 2-23A is redrawn in Fig. 2-23B to show clearly that R_A is in series

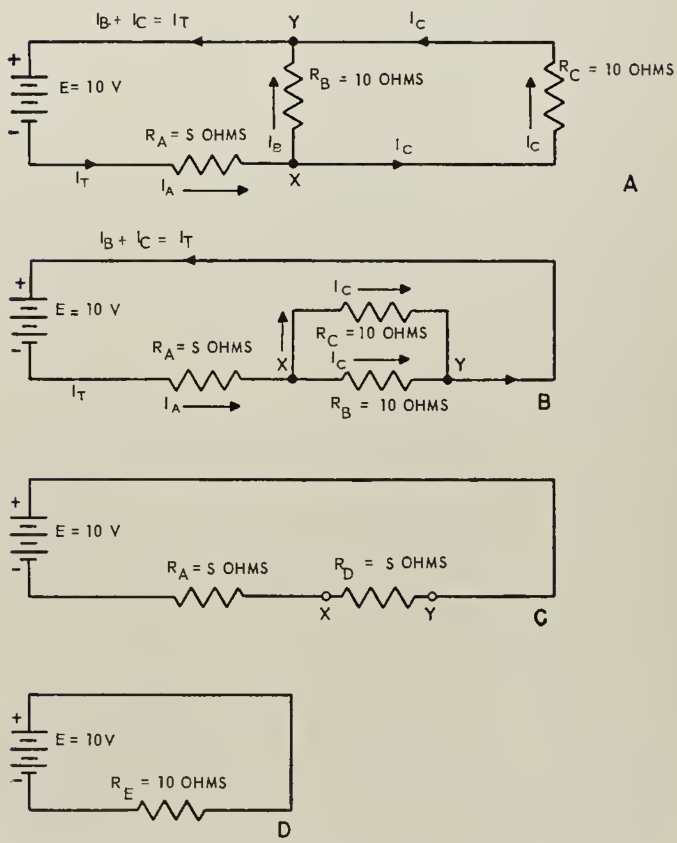


Figure 2-23. Simple series-parallel circuit, solution.

with the parallel resistances R_B and R_C, and that there are two current paths between point X and point Y. The current (I_T) from the battery goes through R_A to point X. At point X the current divides, part (I_B) going through R_B and the remainder (I_C) going through R_C. At Y these two currents reunite ($I_B + I_C = I_T$) and go to the positive terminal and through the battery to the negative terminal.

The battery voltage and the resistance of each resistor is given (Fig. 2-23A), and it is necessary to determine the currents I_T, I_A, I_B, and I_C, the voltage drops E_A, E_B, and E_C, and the effective resistance R_E. Here are the steps to find these:

1. Since all the individual resistances are known, the first step is to determine the effective resistance of the circuit. R_B and R_C are like resistances, and their effective resistance (R_D) is found by the like method:

$$R_D = \tfrac{10}{2} = 5\ \Omega$$

2. This effective resistance R_D is in series with R_A as shown in Fig. 2-23C. The effective resistance R_E of R_A and R_D in series is found by adding the individual resistors:

$$R_E = R_A + R_D = 5 + 5 = 10\ \Omega$$

3. R_E is the effective resistance of the circuit; that is, as far as the battery is concerned, the circuit of Fig. 2-23D is the equivalent of that shown in Fig. 2-23A. Therefore, the current from the battery is

$$I_T = \frac{E}{R_E} = \tfrac{10}{10} = 1\ \text{A}$$

4. Referring to Fig. 2-23A, we see that I_T must go through R_A; that is, $I_A = I_T$. Since we now know the current through R_A, we find the voltage drop E_A from Ohm's law formula $E = IR$:

$$E_A = I_A \times R_A = 1 \times 5 = 5\ \text{V}$$

5. The voltage drop across points X and Y can be found in either of two ways.
   a. The battery voltage E is equal to the sum of the voltage drop E_A across R_A plus the voltage drop E_{XY} across X and Y; that is, $E = E_A + E_{XY}$. Therefore,

$$E_{XY} = E - E_A = 10 - 5 = 5\ \text{V}$$

   b. Since R_B and R_C are equal (10 Ω each), the 1-A current I_T divides equally between them, so that

$$I_B = I_C = \frac{I_T}{2} = \tfrac{1}{2}\ \text{A}$$

   Then,

$$E_{XY} = I_B \times R_B = I_C \times R_C = 0.5 \times 10 = 5\ \text{V}$$

   This agrees with the rule that the same voltage is across each branch of a parallel circuit.

6. In this circuit we determined the branch currents, I_B and I_C, by dividing I_T by 2. Usually, however, the current in each branch must be determined by dividing the voltage across the branch by the resistance in the branch. Thus,

$$I_B = \frac{E_{XY}}{R_B} = \tfrac{5}{10} = 0.5\ \text{A}$$

$$I_C = \frac{E_{XY}}{R_C} = \tfrac{5}{10} = 0.5\ \text{A}$$

When series and parallel circuits are combined, it becomes harder to determine the amount of current flowing in the various branches. In other words, Ohm's law is not always sufficient for determining currents in complicated circuits. The reason is that Ohm's law is a special case of much more general relations. Methods of treating complicated circuits are based on *Kirchhoff's laws.* These laws are simple, but the methods of applying them are difficult. For instance, Kirchhoff's current law states that the current flowing *toward* a point in a circuit must equal the current flowing *away* from that point. Now, if the point divides into two or more paths, note what must occur: The current flowing toward the point must equal the sum of all the lesser currents flowing away from that point. If the two were not equal, some current would

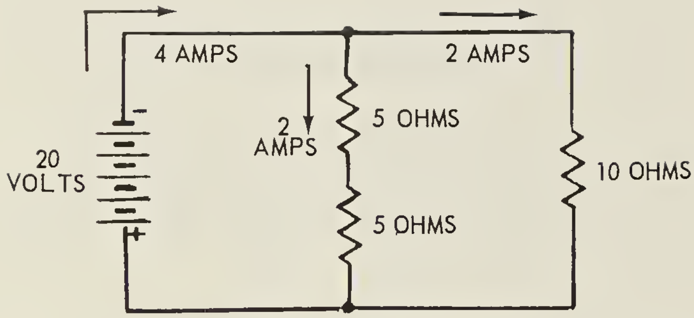


Figure 2-24. Circuit illustrating use of Kirchhoff's current law.

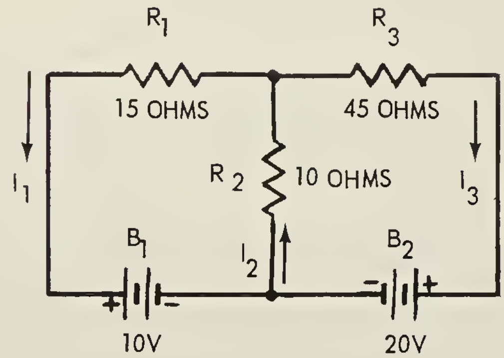


Figure 2-25. Circuit containing both series and parallel branches.

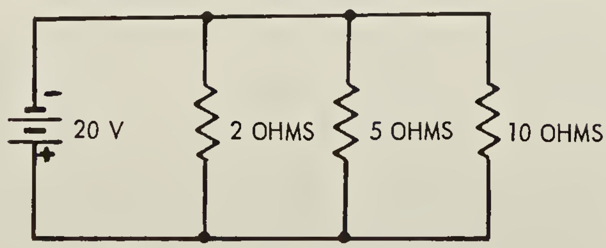


Figure 2-26. A parallel circuit.

remain with no place to go—this is obviously impossible.

The circuit in Fig. 2-24 illustrates Kirchhoff's current law. Note that 4 A of current flow toward point *A*, with 2 A flowing away through the two 5-Ω resistors and 2 A through the 10-Ω resistor. Thus, there are 4 A flowing toward point *A* and 4 A flowing away from point *A*.

When a circuit contains both series and parallel branches, the solution is much more involved. Figure 2-25 illustrates such a circuit. Suppose we want to find the amount of current flowing through R_2. We might think that battery B_2, with a higher voltage than battery B_1, would overpower B_1 and force current through the left-hand circuit. This, however, is not true. The circuit is actually considered as two circuits linked together by the same resistor, R_2. The current through R_2 is made up of two currents, one through R_1 from B_1, and the other through R_3 from B_2.

The formula for Kirchhoff's current law for Fig. 2-26 is

$$I_2 = I_1 + I_3 \tag{2.1}$$

where I_1 = current in amperes through R_1
I_3 = current in amperes through R_3
I_2 = current in amperes through R_2

Kirchhoff's voltage law states that

$$VB_1 = R_1 I_1 + R_2 I_2 = 15I_1 + 10I_2$$

or $$10 = 15I_1 + 10I_2 \tag{2.2}$$

where VB_1 = voltage of battery B_1
R_1 = resistance in ohms of R_1
I_1 = current in amperes through R_1
R_2 = resistance in ohms of R_2
I_2 = current in amperes through R_2

The right-hand circuit is considered in a similar manner:

$$VB_2 = R_2 I_2 + R_3 I_3 = 10I_2 + 45I_3$$

or $$20 = 10I_2 + 45I_3 \tag{2.3}$$

where VB_2 = voltage of battery B_2
R_2 = resistance in ohms of R_2
I_2 = current in amperes through R_2
R_3 = resistance in ohms of R_3
I_3 = current in amperes through R_3

There are now three equations and three unknowns. To solve for the unknowns, we subtract I_3 from both sides of Eq. (2.1):

$$I_1 = I_2 - I_3$$

Substitute this value of I_1 into Eq. (2.2):

$$10 = 15(I_2 - I_3) + 10I_2$$
$$10 = 15I_2 - 15I_3 + 10I_2$$
$$10 = 25I_2 - 15I_3 \tag{2.4}$$

Multiply both sides of Eq. (2.4) by 3:

$$30 = 75I_2 - 45I_3 \qquad (2.5)$$

Add Eqs. (2.3) and (2.5):

$$\begin{aligned} 20 &= 10I_2 + 45I_3 \\ 30 &= 75I_2 - 45I_3 \\ \hline 50 &= 85I_2 + 0 \end{aligned}$$

or

$$I_2 = \tfrac{50}{85}$$

$$I_2 = 0.5882 \text{ A}$$

Substitute this value of I_2 into Eq. (2.3):

$$20 = 10(0.5882) + 45I_3$$

$$20 = 5.882 + 45I_3$$

$$45I_3 = 20 - 5.882$$

$$I_3 = \frac{14.188}{45}$$

$$I_3 = 0.3138 \text{ A}$$

From Eq. (2.1),

$$I_1 = I_2 - I_3$$

$$I_1 = 0.5882 - 0.3138$$

$$I_1 = 0.2744 \text{ A}$$

Therefore,

$$I_1 = 0.2744 \text{ A}$$

$$I_2 = 0.5882 \text{ A}$$

$$I_3 = 0.3138 \text{ A}$$

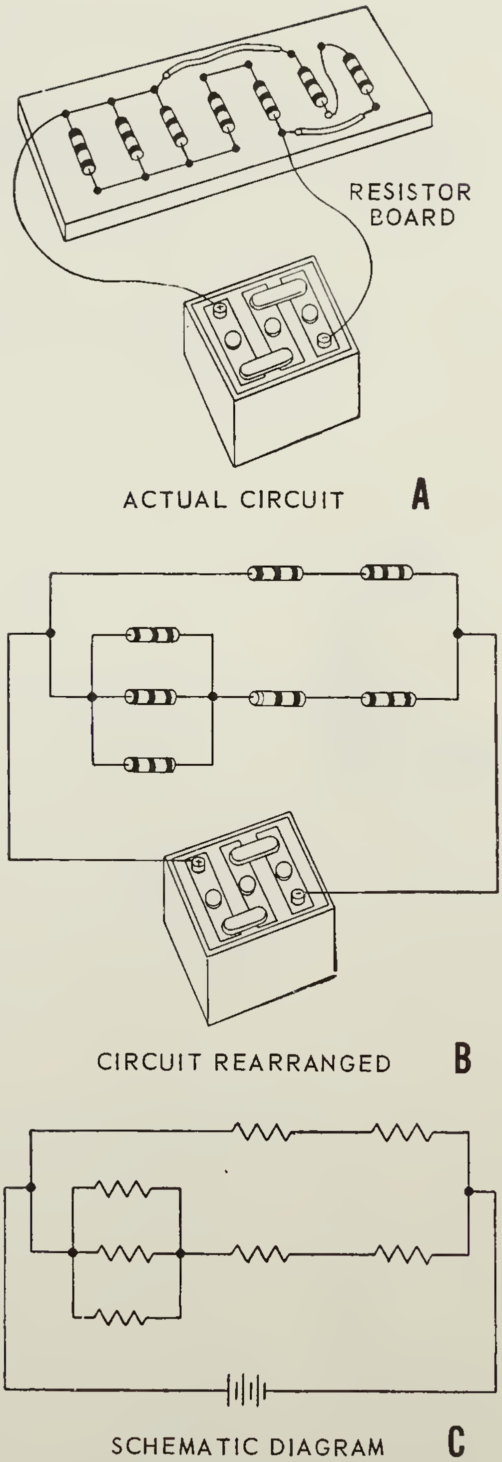


Figure 2-27. Tracing a simple circuit.

Circuit Tracing

The circuits in electrical equipment cannot be identified by a casual examination of the equipment. Most of the parts do not look like the schematic symbols representing them, many of the components are encased, and lead wires are run in cables. For example, a number of the circuit resistors may be mounted on a terminal or resistor board (Fig. 2-27A). At first glance it is not apparent that these resistors are connected as shown in Fig. 2-27B. By carefully tracing the connections of each lead and resistor, the schematic diagram of Fig. 2-27C can be made. In general, manufacturers furnish a schematic diagram with their appliances. Even with such a diagram available, a service technician could not trace the actual circuit without having had considerable experience with electrical equipment. In other words, circuit tracing cannot be learned solely from a book; the book must be supplemented by experience.

Ac theory

CHAPTER

3

An alternating current (ac) continually changes in potential, ranging from zero to maximum voltage and back to zero. In addition, alternating current also periodically changes its direction, from positive to negative and then from negative to positive. This is in contrast to a direct current (dc), which keeps a more-or-less steady potential and flows in one direction only.

PRODUCING ELECTRICITY

Alternating current is the kind of electricity that we are most interested in, for it is the kind we encounter in servicing appliances. It is produced in huge amounts by commercial power stations and is widely distributed throughout the world. It is the most practical type for generation in large quantities, for transmission over long distances, in application to do useful work, and in the use of more trouble-free devices in electric circuits. Remember, though, that the first faltering steps of scientific achievement in the field of electricity were performed with crude and, for the most part, homemade apparatus. Great men such as Georg Ohm had to fabricate nearly all the laboratory equipment used in their experiments. The only convenient source of electric energy available to these early scientists was the voltaic cell, invented some years earlier. Due to the fact that cells and batteries were the only sources of power available, early electrical devices were designed to operate from direct current.

When the use of electricity became widespread, certain disadvantages in the use of direct current became apparent. In a dc system the supply voltage must be generated at the level required by the load. To operate a 240-V lamp, for example, the generator must deliver 240 V. A 120-V lamp could not be operated from this generator by any convenient means. A resistor could be placed in series with the 120-V lamp to drop the extra 120 V, but the resistor would waste an amount of power equal to that consumed by the lamp.

Another disadvantage of dc systems is the large amount of power lost due to the resistance of the transmission wires used to carry current from the generating station to the consumer. This loss could be greatly reduced by operating the transmission line at very high voltage and low current. This is not a practical solution in a dc system, however, since the load would also have to operate at high voltage. As a result of the difficulties encountered with direct current, practically all modern power-distribution systems use alternating current. In an ac system, the current flows first in one direction then reverses and flows in the opposite direction.

Unlike dc voltage, ac voltage can be stepped up or down by a device called a transformer (see p. 71). This permits the transmission lines to be operated at high voltage and low current for maximum efficiency. Then at the consumer end the voltage is stepped down to whatever value the load requires by using a transformer. Due to its inherent advantages and versatility, alternating current has replaced direct current in all but a few commercial power-distribution systems. However, before we study ac generation, let us first take a look at the operation of a dc generator.

Direct-Current Generation

In the preceding chapter it was pointed out that a battery produces a steady, unfluctuating flow of electrons in one direction only. We called this *regular* direct current. A dc generator likewise produces a flow of electrons in one direction only. Due to the method by which it is produced, however, the flow of electrons is unsteady by comparison, and we call it *pulsating* direct current.

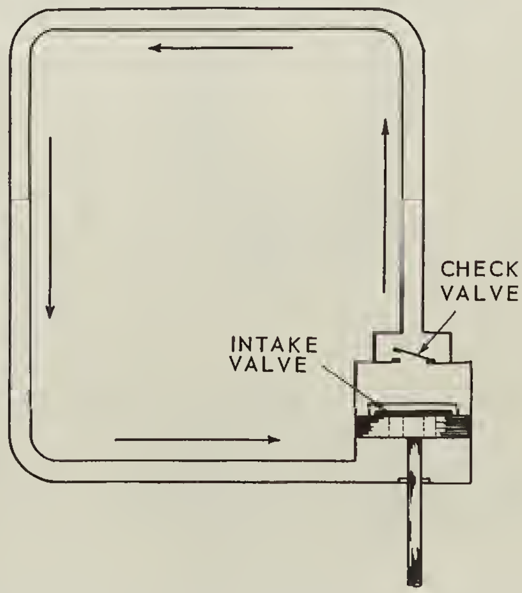


Figure 3-1. Dc action operation as exemplified by a piston-type water pump.

Again using the water analogy, the dc generator may be compared to a piston-type water pump connected to a closed water system, as illustrated in Fig. 3-1. On the upstroke of the piston, the intake valve closes, the check valve opens, and water flows in the direction indicated by the arrows. On the downstroke, the check valve closes, the intake valve opens, and the flow of water momentarily stops until the piston moves upward again. Pulsating direct current can be compared also with the flow of blood in the human body. The blood gets a push every time the heart beats.

Both dc and ac generators, as defined earlier, convert mechanical energy into electric energy. They do this by utilizing the principle of *electromagnetic induction.* In the study of magnetism (Chap. 1), it was shown that a current-carrying conductor produces a magnetic field around itself. It is also true that a changing magnetic field may produce an emf (electromagnetic field) in a conductor. If a conductor lies in a magnetic field, and either the field or conductor moves, an emf is induced in the conductor. This effect is called *electromagnetic induction.*

Regardless of the complexity of any generator, there are only three elements involved. First, a magnetic field, produced by magnets; second, an armature for carrying a coil of wire through the field; and third, a prime mover to turn the armature. The two essential parts of a generator are shown in Fig. 3-2. Part A shows the stationary frame, which includes the yoke and base with the two pole pieces. In this case, the pole pieces are magnetized permanently. The armature, shown at B, consists of a series of copper wires looped around an iron core and a commutator. The commutator is a series of copper segments to which the ends of the wires are attached.

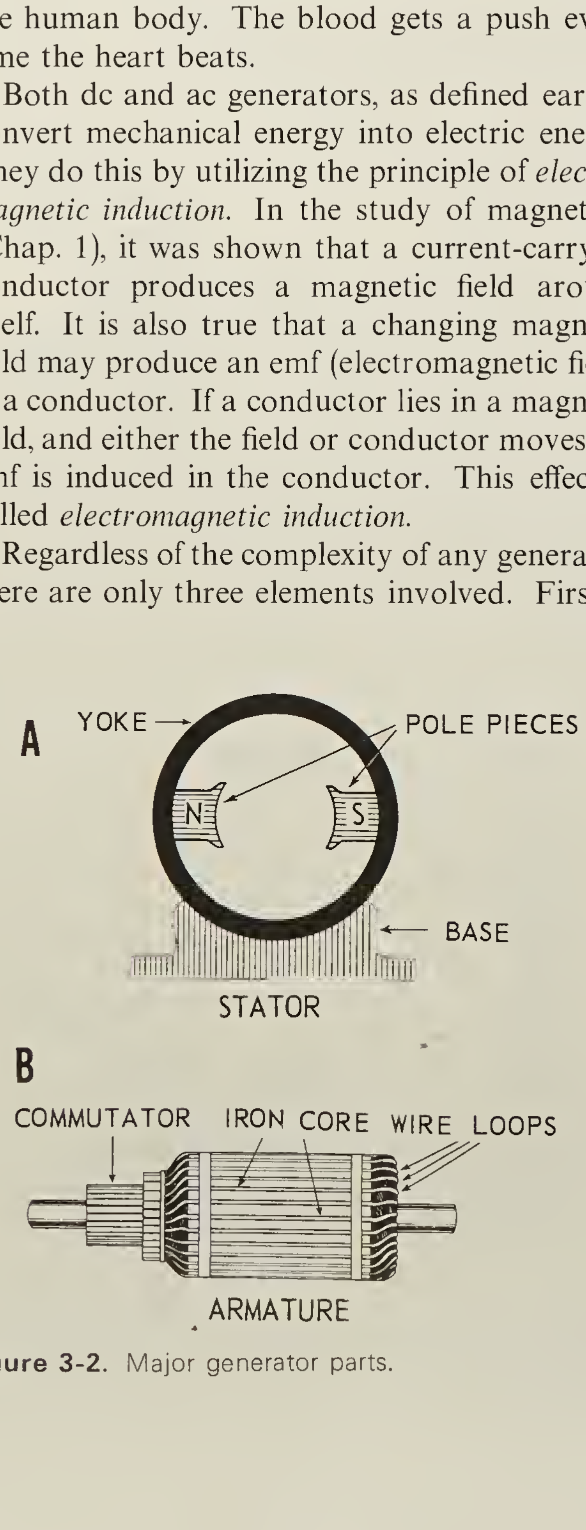


Figure 3-2. Major generator parts.

To better understand what happens in an armature, one turn of the coil and two segments of the commutator have been lifted from the armature and placed in the magnetic field of the pole pieces as illustrated at B.

Dc generator action. In Fig. 3-3, the four views of a coil in a magnetic field are shown. At each end of the coil is a segment of the commutator, and against the segments are carbon blocks called *brushes.* This arrangement provides a slipping contact between the rotating armature and the stationary load. For the sake of clarity, one-half of the coil and one segment are black and the other half of the coil and the other segment are white. Note the direction of magnetic flux and the direction of rotation.

In Fig. 3-3A, no voltage is produced, because the coil is cutting no lines of flux and in this position the brushes are contacting only the insulation between the segments. In Fig. 3-3B, the coil has moved at right angles. The black side of the coil is cutting downward, and the white side is cutting upward. This causes the induced voltage in the coil to flow "in" the white side of the coil and "out" the black side.

In Fig. 3-3C the armature has been turned another quarter-turn, and further note that in Fig. 3-3C the same condition is apparent as in Fig. 3-3A except that the coil is upside down. Again the flow of current has stopped, because the conductor is no longer cutting the lines of force.

In Fig. 3-3D, the coil is the opposite position from Fig. 3-3B. Now the black side is cutting upward and the current is flowing in, and the

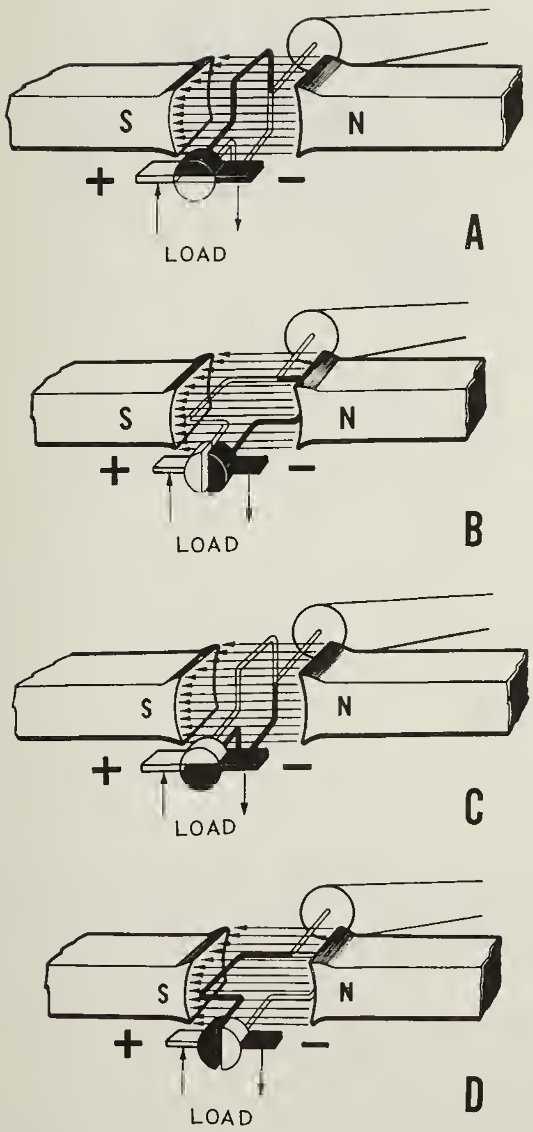


Figure 3-3. A dc generator action.

white side is cutting downward and the current is flowing out. Since half of the time the current in the black portion of the coil is flowing in and the other half of the time it is flowing out, it can be said that alternating current is flowing inside the coil. In fact, a rotating coil in a magnetic field always produces alternating current. How the alternating current in the loop is caused to flow in only one direction to a load is illustrated in Fig. 3-3D.

In Fig. 3-3B and 3-3D, the black brush is marked negative, while the white is considered positive. The brushes are stationary, and when current is flowing the negative brush is always in contact with the segment of the coil having current "out." The segment attached to the side having current "in" is always in contact with the positive brush. So, if it is desired to deliver dc current to a load, a commutator is always used. Since the commutator causes the alternating current in the armature to be delivered to the load in one direction, it is said to rectify the current. A single coil rotating in a magnetic field is like an automobile hitting on one cylinder. The output is weak and fluctuating.

Figure 3-4 illustrates the dc voltage produced by a single loop rotating in a magnetic field. When the black portion of the loop is in the upward position, no lines of force are being cut and no voltage is produced. As the loop turns in a clockwise direction, the black portion progressively cuts more lines of force and the voltage progressively increases to the maximum. As the black portion of the loop progresses toward the downward position, the voltage decreases to zero. The loop is again in the vertical position. At this point, the white portion of the loop begins to cut the lines of force in a downward direction as the black portion cuts them in an upward direction. This causes the voltage to increase to its maximum when the loop is horizontal, and to decrease again to zero when the white portion has progressed to the downward position. Since during this process the black commutator has moved to the white brush and the white commutator has moved to the black brush, the current flows to and from the load in the same direction

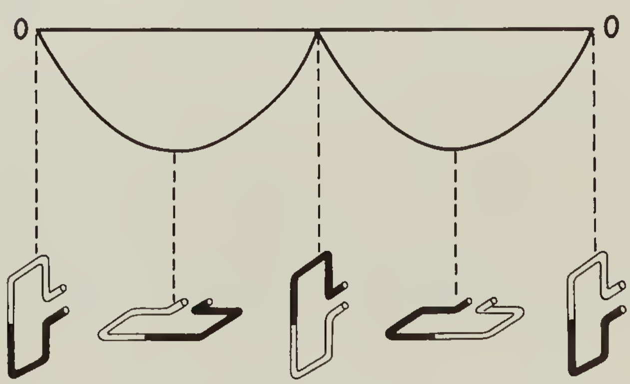


Figure 3-4. A graph of dc voltage and current (single loop).

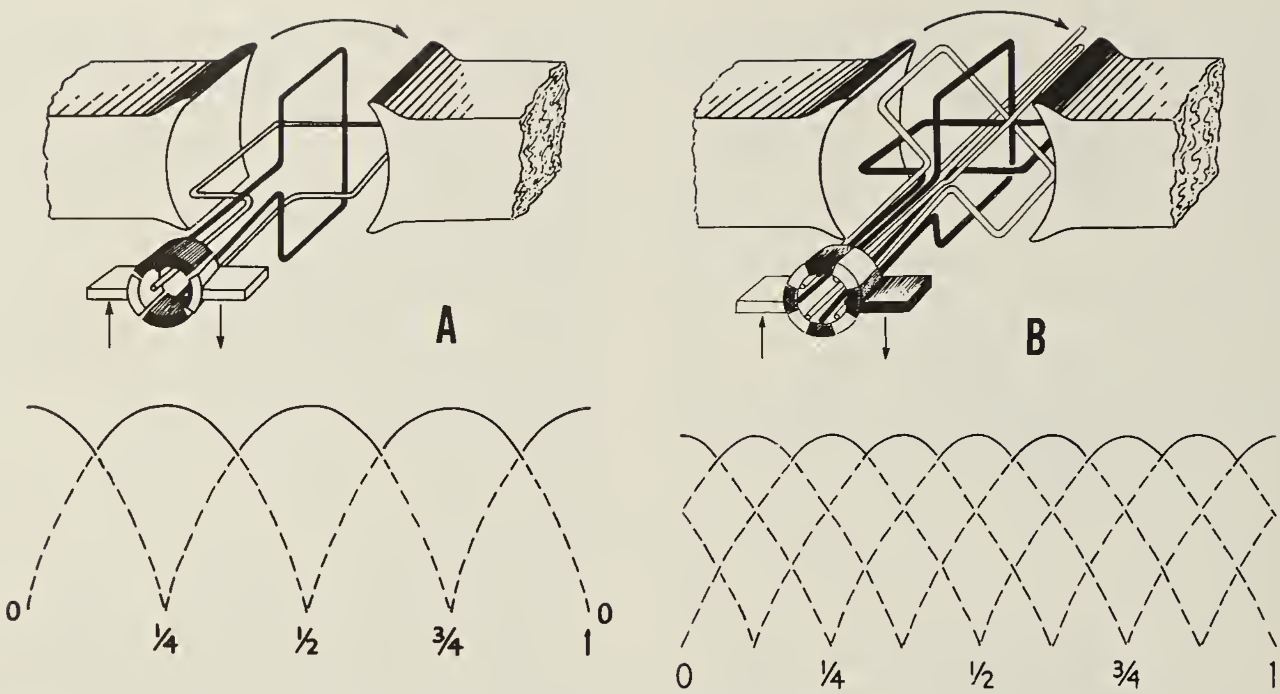


Figure 3-5. Two-coil (A) and four-coil (B) generators and their graphs.

as it did before the commutator and brushes changed relationship. From this we can readily see that even if a one-loop coil were capable of producing sufficient current to light a bulb, the light would go out every time the voltage dropped to zero. The fluctuation of voltage can be reduced by increasing the number of loops and commutator segments. How this is accomplished is illustrated here.

In Fig. 3-5A, an armature, with two loops and a four-segment commutator, is shown. When this armature is rotated, the black coil is going to be one-quarter of a revolution behind the white coil. This means that the voltage of the black coil is at zero when that of the white coil is at its maximum. However, the brushes riding on the commutator contact only the coil producing the greater voltage. The heavy part of the graph indicates the voltage picked up by the brushes. Notice that the voltage is more level than it was with one coil. It is still pulsating current, but it does not get all the way down to zero.

In Fig. 3-5B, a four-coil armature with eight segments in the commutator is substituted for the two-coil armature. As before, when the armature is rotated, the brushes pick up only the very peaks of each coil's voltage. This is still pulsating dc, but only slightly so. The rise and fall is very short, as shown on the graph. Obviously, if voltage without fluctuation is desired, all that is necessary is to add sufficient coils and to increase the number of segments proportionately.

Alternating-Current Generation

While direct current, either regular or pulsating, is a one-way flow of electrons, alternating current first flows in one direction, then reverses and flows in the opposite direction.

A water analogy can be used to illustrate alternating current in Fig. 3-6. In the illustration, a pump with a solid piston and pipes containing water are shown. If the piston is moved upward, the water flows in a counterclockwise direction, as indicated by the arrows. Pulling the piston downward causes the water to flow in the opposite direction.

Ac generator action. Now, what do we do if we want to supply alternating current to the load? This is quite simple. Since we produce alternating current in the rotating coil of any gen-

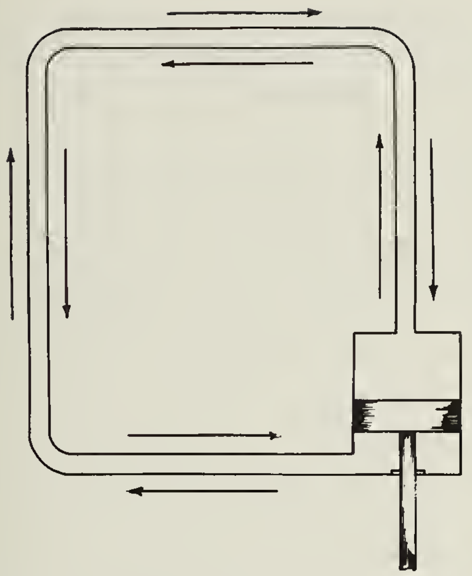


Figure 3-6. Ac operation of a piston-type water pump.

erator, it is just a matter of eliminating the rectifying commutator and employing slip rings, as illustrated in Fig. 3-7.

Instead of connecting each end of the coil to a commutator segment or half a ring, each end is connected to a complete ring which is in contact with a brush at all times. A view of the coil in a vertical position has been omitted for this explanation.

In Fig. 3-7A, the current is flowing "out" the black portion of the coil and flowing "in" through the white portion. The black ring and brush will be called negative, and the white ring and brush we shall call positive. In Fig. 3-7B, the coil has rotated through the neutral plane, and the black portion now cuts upward. Now the current reverses, flowing "in" through the black ring and brush and "out" through the white ring and brush. This reverses the current through the load; the white brush becomes negative and the black becomes positive.

Figure 3-7 shows a graph of the ac voltage produced by a single loop rotating counterclockwise in a magnetic field. For ease of explanation, the loop has been divided into a dark and a light half. Notice that, in part A, the dark half is moving along (parallel to) the lines of force. Consequently, it is cutting none of these lines. The same is true of the light half,

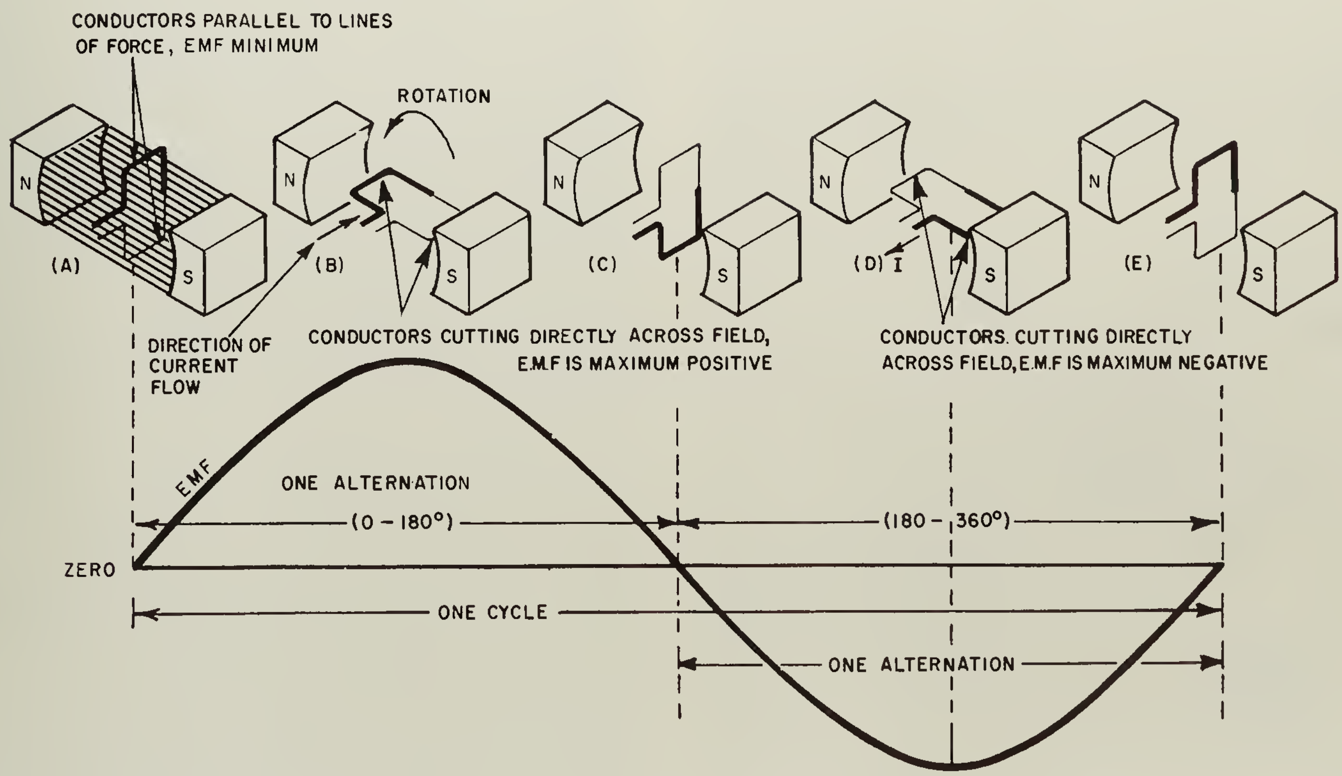


Figure 3-7. Basic ac generator.

moving in the opposite direction. Since the conductors are cutting no lines of force, no emf is induced. As the loop rotates toward the position shown in part B, it cuts more and more lines of force per second because it is cutting more directly across the field (lines of force) as it approaches the position shown in B. At position B the induced voltage is greatest because the conductor is cutting directly across the field. As the loop continues to be rotated toward the position shown in C, it cuts fewer and fewer lines of force per second. The induced voltage decreases from its peak value. Eventually, the loop is once again moving in a plane parallel to the magnetic field, and no voltage (zero voltage) is induced. The loop has now been rotated through half a circle (one alternation, or 180°). The sine curve shown in the lower part of the figure shows the induced voltage at every instant of rotation of the loop. Notice that this curve contains 360°, or two alternations. Two alternations represent one complete *cycle* of rotation.

The direction of current flow during the rotation from B to C, when a closed path is provided across the ends of the conductor loop, can be determined by using the *left-hand rule for generators.* The left-hand rule is applied as follows: Extend the left hand so that the thumb points in the direction of conductor movement and the forefinger points in the direction of magnetic flux (North to South). Point the middle finger 90° from the forefinger. The middle finger will point in the direction of current flow within the conductor (Fig. 3-8).

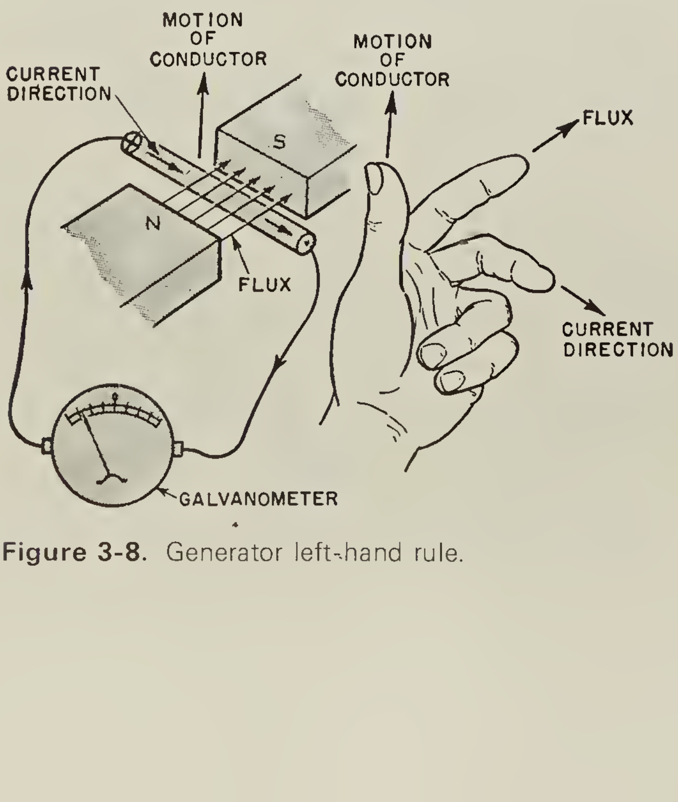


Figure 3-8. Generator left-hand rule.

By applying the left-hand rule to the dark half of the loop in part B, the direction of current flow can be determined. This direction is depicted by the heavy arrow. Similarly, the direction of current flow through the light half of the loop can be determined. The two induced voltages add together to form one total emf. When the loop is further rotated to the position shown in D, the action is reversed. The dark half is moving up instead of down, and the light half is moving down instead of up. By applying the left-hand rule once again, it is readily apparent that the direction of both the induced emf and its resulting current have reversed. The voltage builds up to maximum in this new direction, as shown by the sine-wave tracing. The loop finally returns to its original position (part E), at which point the voltage is again zero. The wave of induced voltage has gone through one complete cycle. [As mentioned previously, the cycle is two complete alternations in a period of time. Recently, the *hertz* (Hz) has been designated to be used in lieu of *cycles per second* (cycles/s). While it may seem confusing to the reader that in one place a cycle is used to designate two alternations per period of time and in another instance a hertz is used to designate two alternations per second, the key to determine which is used is the time factor. 1 Hz = 1 cycle/s. Therefore, throughout this manual a cycle is used when no specific time element is involved and a hertz is used when the time element is measured in seconds.]

As in the dc generator, a single loop would produce a very weak and fluctuating current and voltage. While the strength of alternating current and voltage can be increased by adding more loops to the slip rings, the fluctuation cannot be changed in this manner. Fluctuation can be overcome and controlled by increasing the speed of the armature and keeping this speed constant. That is, if the loop is rotated at a steady rate, and if the strength of the magnetic field is uniform,

the number of hertz and the voltage will remain at fixed values. Continuous rotation will produce a series of sine-wave voltage cycles, or, in other words, an ac voltage.

Frequency. The frequency (f) of an alternating current or voltage is the number of complete cycles occurring in each second of time. Hence, the speed of rotation of the loop determines the frequency. For a single loop rotating in a two-pole field, you can see that each time the loop makes one complete revolution, the current reverses direction twice. A single hertz will result if the loop makes one revolution each second. If it makes two revolutions per second, the output frequency will be 2 Hz. In other words, the frequency of a two-pole generator happens to be the same as the number of revolutions per second. As the speed is increased, the frequency is increased.

If an alternating-current generator has four pole pieces, as shown in Fig. 3-9, every complete mechanical revolution of the armature will produce 2 ac cycles. When the dark half of the loop passes between poles S1 and N2, a voltage is induced which causes current to flow into the slip ring attached to the dark end of the loop.

When the dark half passes between N2 and S2, the induced voltage reverses direction. Another reversal occurs when it passes between S2 and N1. The voltage at the slip rings reverses direction *four times* during each revolution. In other words, 2 cycles of ac voltage are generated for each mechanical revolution. If each revolution lasts 1 s, the frequency of the output is 2 Hz. The more poles that are added, the higher the frequency per revolution becomes. To find the output frequency of any ac generator, the following formula can be used:

$$f = \frac{P \times \text{r/min}}{120}$$

where f = frequency, Hz
r/min = revolutions per minute
P = the number of poles

A generator made to deliver 60 Hz and having two field poles would need an armature designed to rotate at 3,600 r/min. If it had four field poles,

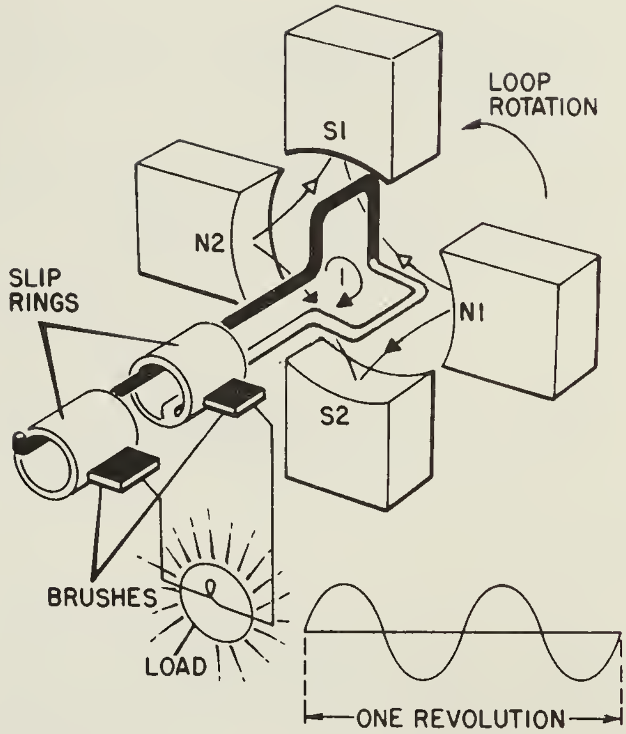


Figure 3-9. Four-pole basic ac generator.

it would need an armature designed to rotate at 1,800 r/min. In either case, the frequency would be the same. In actual practice, a generator designed for low-speed operation generally has a greater number of pole pieces, while a high-speed machine will have relatively fewer pole pieces, if both are to deliver power at the same frequency.

Remember that all electrically operated devices, except heater elements, must be designed for the same cycle of current as that produced by the generator. For example, a 60-Hz clock motor will operate on 50-Hz current, but the clock will run slow and not keep the proper time. Likewise, a 60-Hz motor for a refrigerating system will operate on 50-Hz current, but the capacity of the system will be reduced proportionately. Because of this, modern power plants are equipped with elaborate and relatively complex devices to accurately control the speed of both the turbines and the generators.

Period. An individual cycle of any sine wave represents a finite amount of time. Figure 3-10 shows 2 cycles of a sine wave which has a

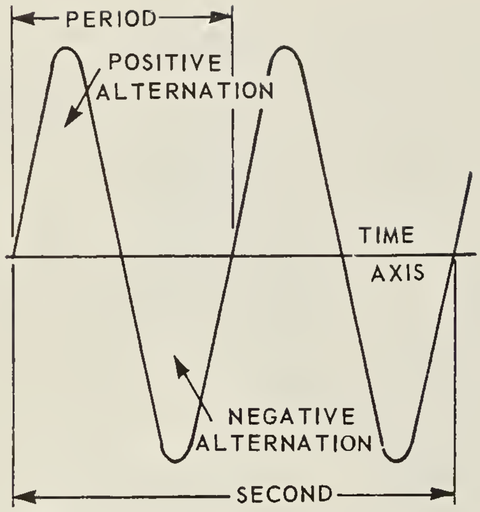


Figure 3-10. Period of a sine wave.

frequency of 2 Hz. Since 2 cycles occur each second, 1 cycle must require $\frac{1}{2}$ s. The time required to complete 1 cycle of a waveform is called the *period* of the wave. In this example the period is $\frac{1}{2}$ s.

Each cycle of the waveform in Fig. 3-10 is seen to consist of two pulse-shaped variations in voltage. The pulse which occurs during the time the voltage is positive is called the *positive alternation.* The pulse which occurs during the time the voltage is negative is called the *negative alternation.* For a sine wave these two alternations will be identical in size and shape, and opposite in polarity.

The period of a wave is inversely proportional to its frequency. Thus, the higher the frequency (greater number of hertz), the shorter the period. In terms of an equation,

$$t = \frac{1}{f}$$

where t = period, in seconds
f = frequency, in hertz

Sine-curve generation. Figure 3-11 shows a coil side in eight positions, spaced 45° around the axis of rotation. The rotation of the coil is counterclockwise, and the heavy arrows show the velocity of the conductor at each position. In each position the angle of rotation will determine the number of lines of force cut by the conductor, since at 0°, 180°, and 360° no lines will be cut, and at 90° and 270° a maximum number will be cut. It should be noted that the number of lines cut is not proportional to the angle itself but to the sine of the angle; and since the emf induced in the coil is proportional to the number of lines of force cut by the conductor, the emf induced at each position, therefore, will be proportional to the sine of the angle of rotation of the conductor. At positions 1 and 5, the conductor is moving parallel to the lines of force and the induced emf is zero. This corresponds to 0° and 180° on the time axis of the sine curve. At positions 3 and 7, the conductor cuts the flux lines at right angles and the emf is a maximum. This corresponds to 90° and 270° on the sine curve. The horizontal or X axis of the sine curve represents time, and one complete cycle represents the period of rotation of the coil. Therefore, the time axis may be divided directly into mechanical degrees of rotation. A quarter-turn of the conductor is one-quarter of the time of 1 cycle and therefore is marked as 90° rather than actually in fractions of seconds of time. The vertical or Y axis is a measure of the sine of the angle of rotation of the conductor, and since this sine is proportional to the emf, it may be divided directly into units of voltage or current.

The part of the sine curve above the horizontal axis is called the positive half-cycle or alternation, and the part below the line is called the negative half-cycle or alternation. This use of the terms positive and negative refers to the direction of the induced emf in reference to a fixed position, the negative voltage being in the opposite direction from the positive and occurring in time 1 half-cycle later. It will be remembered that the direction of the induced emf at each position of the coil side was obtained by application of the right-hand screw rule. Thus, whether the first half-cycle of the sine curve of Fig. 3-11 is positive or negative depends on whether the generator is rotated counterclockwise or clockwise.

Phase. The term *phase* applies only to alternating current, because of the manner in which current is generated and transmitted by the power company and the manner in which it is utilized by an electric component such as a motor.

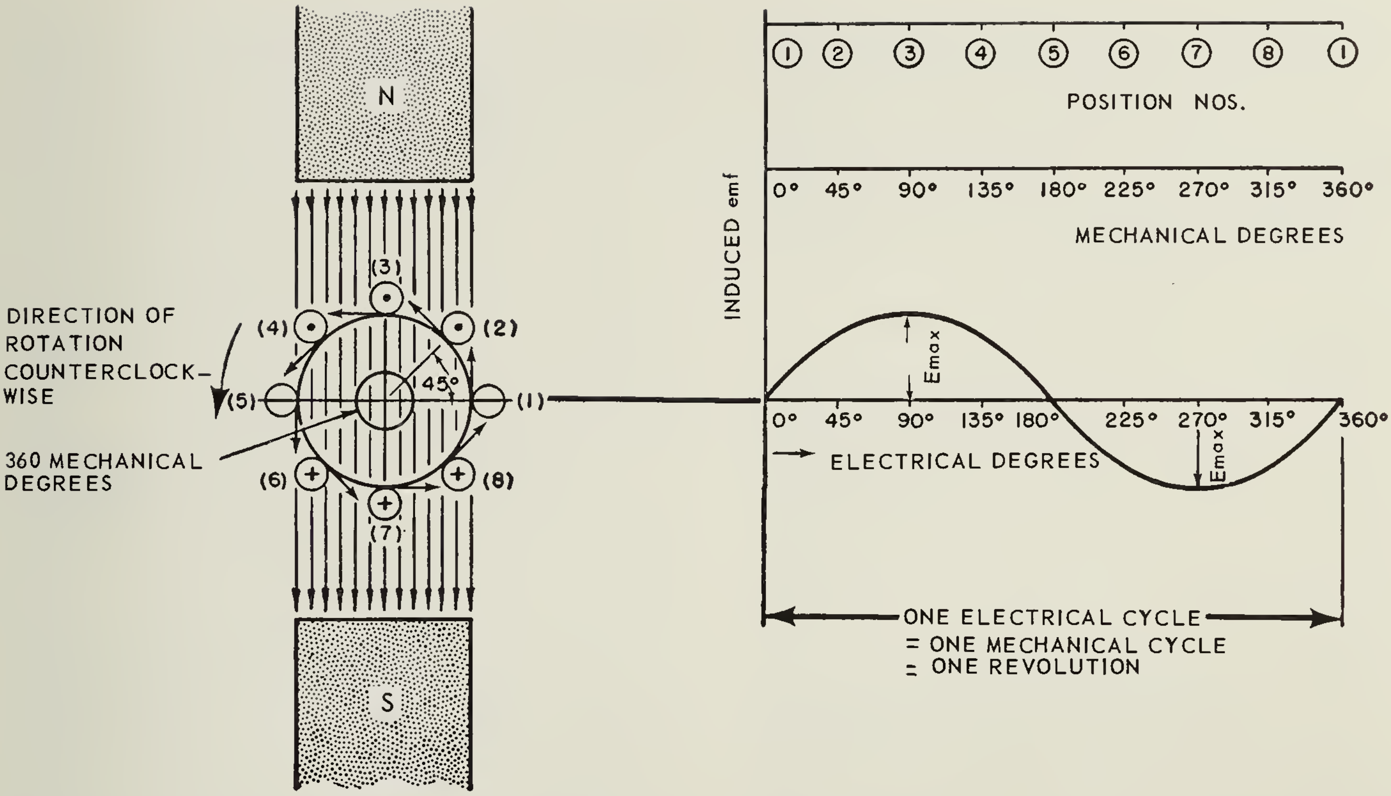


Figure 3-11. Generation of sine wave voltage (single-phase ac generator).

The terms *single-phase, split-phase, polyphase,* and *three-phase* are relatively common in use, especially in conjunction with the type of motor used.

Single-phase generators and motors have only one set of windings embedded in their stators, and only two wires are connected externally for conducting the incoming and outgoing voltage and current.

Split-phase applies only to a type of motor; there are no split-phase generators. This type of motor has two sets of windings embedded in the stator, one set of which is usually for starting purposes. The motor, however, has only two external leads and operates on single-phase generated current. The manner in which split-phase and other motors designed for single-phase current operate will be discussed in Chap. 5.

The word "poly," in the Greek language, means many. A polyphase generator, therefore, is one that has two or more sets of windings embedded in its stator. A true polyphase motor has the same number of sets of windings as the generator from which it receives its current. No special windings are required for starting. Except for a very few exceptions, all polyphase equipment is made for three-phase current.

As the name implies, three-phase current is that produced by a generator having three separate sets of stator windings. A three-phase motor, therefore, must also have three sets of main stator windings. The manner in which the windings are placed and connected in three-phase generators and motors, as well as other basic information relative to three-phase current, will be covered in Chap. 5.

The use of three-phase current is usually confined to business establishments and industrial plants. This is because their equipment uses larger motors that require much larger quantities of current than that required for domestic applications. Because of the cost involved in distribution and in equipment construction, practically all homes are supplied with single-phase alternating current only. The symbol Φ is the Greek letter "phi," which is used to designate

the phase of a current. For example, 1 Φ means single-phase and 3 Φ means three-phase.

The generation and utilization of single-phase current can be more readily understood than can three-phase. Also, a majority of the service complaints we are called upon to diagnose are on single-phase equipment.

Values of Alternating Voltage or Current

There are three important values associated with sine waves of voltage or current: *maximum*, or *peak*, designated as E_m or I_m; *average*, designated as E_{avg} or I_{avg}; and *effective*, designated as E or I.

Peak amplitude. One of the most frequently measured characteristics of a sine wave is its *amplitude*. Unlike dc measurement, the amount of alternating current or voltage present in a circuit can be measured in various ways. In one method of measurement, the maximum amplitude of either the positive or the negative alternation is measured. The value of current or voltage obtained is called the *peak voltage* or the *peak current*. To measure the peak value of current or voltage, an oscilloscope or a special meter (peak-reading meter) must be used. The peak value of a sine wave is illustrated in Fig. 3-12.

A second method of indicating the amplitude voltage or current is to measure the distance between the positive and negative peaks. This value of current or voltage is called the *peak-to-peak value* (Fig. 3-12). Since both alternations of a pure sine wave are identical, the peak-to-peak value is twice the peak value. Peak-to-peak voltage is usually measured with an oscilloscope, although some voltmeters have a special scale calibrated in peak-to-peak volts.

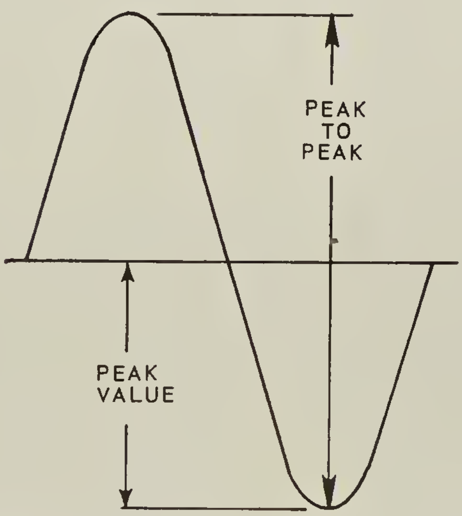


Figure 3-12. Peak and peak-to-peak values.

Effective or rms value. As the use of alternating current gained popularity, it became increasingly apparent that some common basis was needed on which alternating current and direct current could be compared. A 100-W light bulb, for example, should work just as well on 120 V ac as it does on 120 V dc. It can be seen, however, that a sine wave of voltage having a peak value of 120 V would not supply the lamp with as much power as a steady value of 120 V dc.

To properly compare ac with dc, engineers devised what is known as *root mean square* (rms) current. That is, one rms ampere of alternating current is as effective in producing heat as one steady ampere of direct current. For this reason an rms ampere is also called an *effective* ampere. Anytime an alternating voltage or current is stated without any qualification, it is assumed to be an effective value. Since effective values of alternating voltage and current are the ones generally used, most meters are calibrated to indicate effective values of voltage and current.

In many instances it is necessary to convert from effective to peak or vice versa. By calculation, the peak value of a sine wave is 1.414 times the effective value and therefore

$$E_m = E \times 1.414$$

where E_m = maximum or peak voltage
E = effective or rms voltage

and

$$I_m = I \times 1.414$$

where I_m = maximum or peak current
I = effective or rms current

Upon occasion it is necessary to convert a peak value of current or voltage to an effective value. The conversion factor may be derived as follows:

$$E_m = E \times 1.414$$

Multiplying both sides of the equation by 1/1.414

$$E_m \times \frac{1}{1.414} = E \times 1.414 \times \frac{1}{1.414}$$

$$E_m \times \frac{1}{1.414} = E$$

Dividing 1 by 1.414,

$$E = E_m \times 0.707$$

where E = effective voltage
E_m = maximum or peak voltage

Similarly, for current,

$$I = I_m \times 0.707$$

where I = effective current
I_m = maximum or peak current

Average value. The average value of a complete cycle of a sine wave is zero, since the positive alternation is identical to the negative alternation. In certain types of circuits, however, it is necessary to compute the average value of one alternation. This can be accomplished by adding together a series of instantaneous values of the wave between 0 and 180° and then dividing the sum by the number of instantaneous values used. Such a computation would show one alternation of a sine wave to have an average

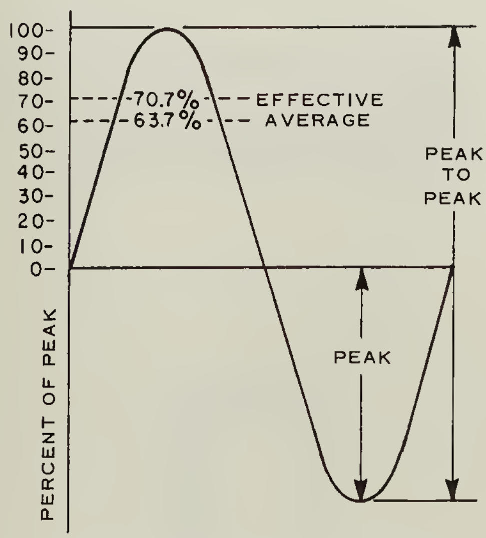


Figure 3-13. Various values used to indicate sine wave amplitude.

value equal to 0.637 of the peak value. In terms of an equation,

$$E_{avg} = E_m \times 0.637$$

where E_{avg} = average voltage of one alternation
E_m = maximum or peak voltage

Similarly,

$$I_{avg} = I_m \times 0.637$$

where I_{avg} = the average current in one alternation
I_m = the maximum or peak current

Figure 3-13 shows a comparison between the various values that are used to indicate the amplitude of a sine wave.

ELECTROMAGNETISM

Until now, we have established only the basic principle of producing electricity by magnetism as applied to dc and ac generators having a rotating armature in a stationary magnetic field. In order to understand the production of voltage and current in a modern ac generator, as well as the basic principles of transformers and other electric components, a knowledge of electromagnetism is required. As the name implies, electromagnetism is the production of magnetism by an electric current.

Electromagnets. As was stated in Chap. 1, an electromagnet is like a natural or artificial magnet in its attraction, but it differs in its control. Although an electromagnet can be powerful in its attraction, it can be turned on and off with the flick of a switch. Electromagnets are used to lift heavy pieces of metal from one place to another, to open or close contacts in relays, to open orifices in solenoid valves, and to turn rotors in dynamos and motors.

In Fig. 3-14, a dry cell with a wire connected from the negative to positive terminal is shown. The wire has been dipped into a pile of iron filings and some of the filings are clinging to the wire. This proves that any conductor carrying

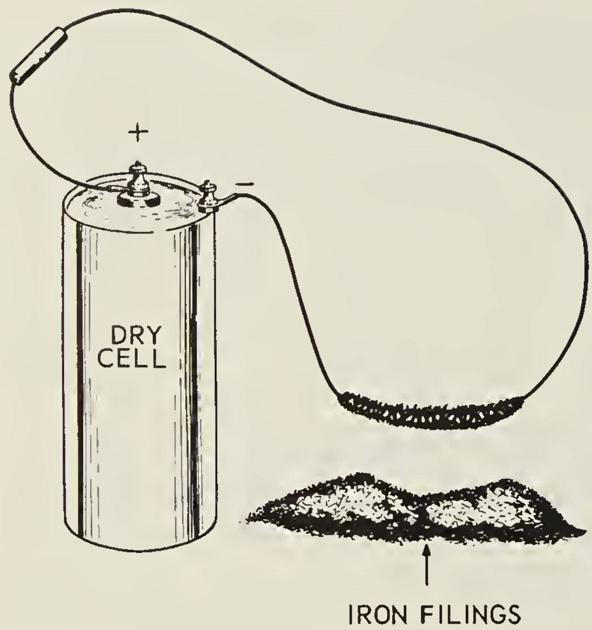


Figure 3-14. Magnetism by current.

an electric current is surrounded by a field of flux, or magnetic field. If one end of the wire is disconnected from the dry cell, the filings drop off. This proves that the field exists only when current is flowing. Although the filings are shown clinging only to a portion of the wire, the field actually surrounds the wire for its entire length.

Although a field of flux or magnetism has been produced with a straight, single conductor, no polarity is apparent. To be able to put magnetism by electricity to a practical application, poles must be produced. To produce poles, simply form the straight conductor into a loop as shown in Fig. 3-15.

When a conductor is formed into a loop the flux bends toward the center of the loop and produces a north pole on one side and a south pole on the other. If a small number of loops of wire are combined, they form a *helix coil*, which produces much stronger poles than a single loop. If a very strong magnetic coil is desired, more turns of wire are built up in layers. This produces a *solenoid coil*.

If a solenoid coil is wound around a piece of iron or other easily magnetized metal, the metal is called the *core* or *pole piece*. When the coil is energized, the core becomes temporarily magnetized and an electromagnet has been produced. The core of an electromagnet has a low retentivity (high permeability) and immediately becomes demagnetized when the flow of current ceases. Without this characteristic, electromagnets would have little practical use.

Figure 3-16 illustrates a basic electromagnet.

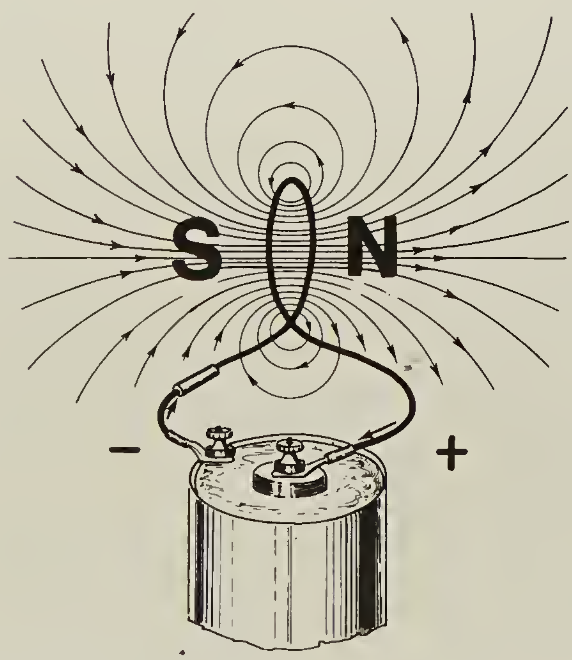


Figure 3-15. Magnetic polarity of a loop.

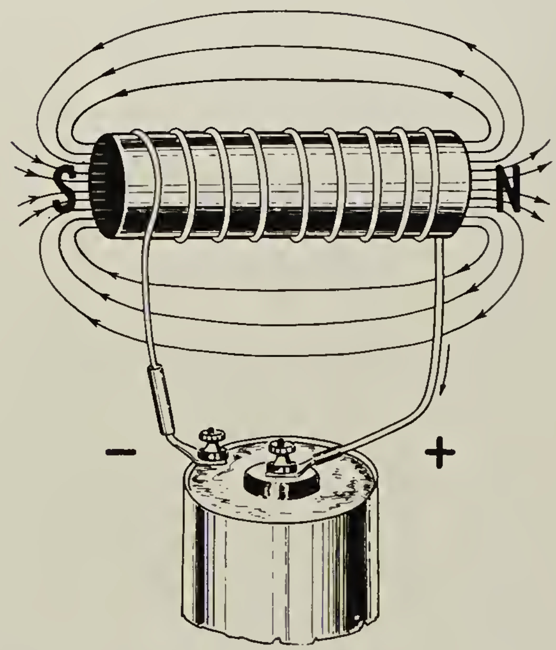


Figure 3-16. A basic electromagnet.

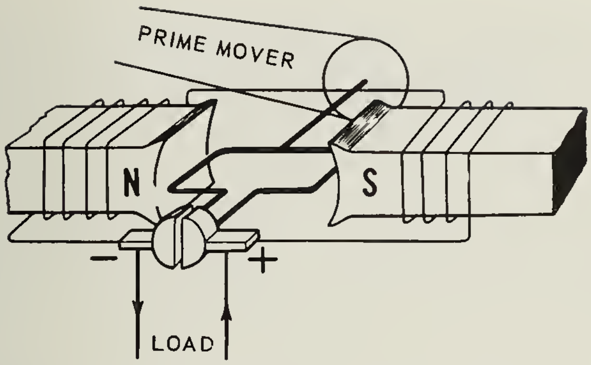


Figure 3-17. Electro-magnetism applied to a dc generator.

For the sake of clarity, the illustration shows very few loops of wire as compared with the number actually required. Electromagnets can be produced by using either direct or alternating current.

Having established the basic principles of an electromagnet, let us first discuss the role electromagnetism plays in the generation of current. Figure 3-17 shows how the magnetism in the pole pieces of a dc generator can be strengthened. Here we see that the pole pieces are wound with coils of wire which are connected to the brushes. In operation, some of the current produced by the generator is used to strengthen its own poles. An electromagnet can always produce a stronger field than a permanent magnet. A permanent magnet also can be strengthened by winding an energized coil around it. Actually, the strength, or intensity, of a coil's field depends on a number of factors. The major factors are listed here:

1. The number of turns of conductor
2. The amount of current flow through the coil
3. The ratio of the coil's length to its width
4. The type of material in the core

We next ask how the proper polarity of the pole pieces of the generator is established and maintained. It is done by winding the poles in the opposite direction. For example, if the pole marked N were wound in the same direction as the S pole, it would also become an S pole, and there would be no current generated by the rotating loop.

Electromagnetism and AC Generation

Although the simple ac generator previously illustrated and described could produce voltage and current, they would both be too weak to be of practical value. By increasing the number of rotating loops and by strengthening the magnetic field by electromagnetism, stronger voltage and current can be produced. Unlike dc generators, ac generators cannot share their current to self-strengthen their pole pieces because of their inability to maintain constant polarity of the poles. They can, however, be strengthened by electromagnetism produced by current supplied from a separate dc generator. All modern power plants use dc generators to strengthen, or excite, a magnetic field for ac generators. When so employed, the dc generator is called an *exciter*, and the ac generator is called an *alternator*. The term "alternator" will be used throughout the remainder of the course in connection with the generation of alternating current.

Alternators. There are two basic types of alternators. Figure 3-18 illustrates the *rotating-armature* type used in the early days of ac

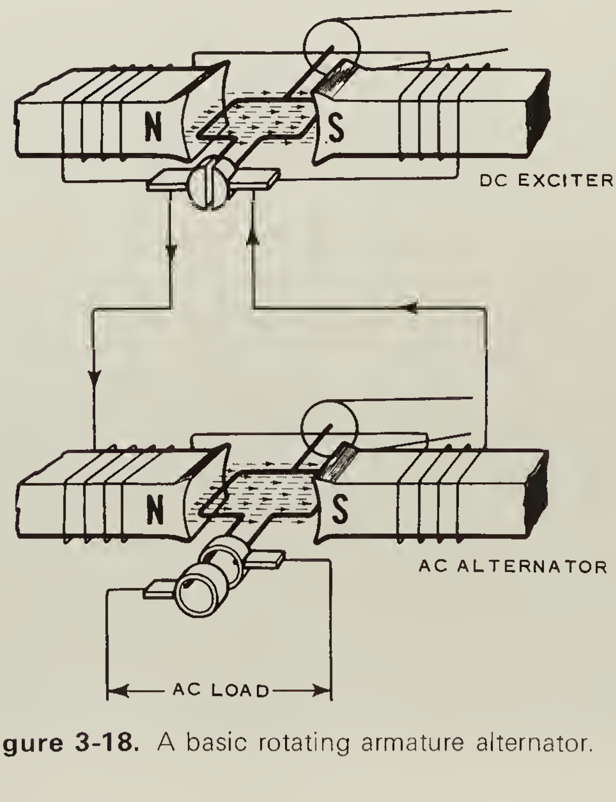


Figure 3-18. A basic rotating armature alternator.

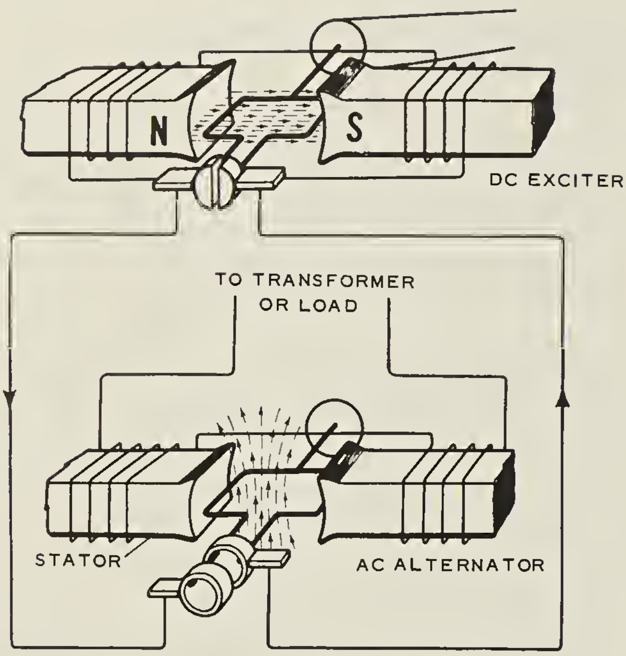


Figure 3-19. A basic rotating field alternator.

generation. A few of these may be found in operation today in small communities. Here we note that the dc exciter is used to strengthen the stationary field, through which the rotating armature passes. It should be remembered that both the dc exciter and the alternator require a prime mover. In some instances each have their own turbine, while in most instances the same turbine is used for both. Although this type of alternator pioneered ac generation, it had construction limitations which made it unsuitable for the high voltages and currents required for modern long-distance transmission.

Figure 3-19 illustrates the basic design of a later development, called the *rotating-field* type, which embodies the principles of all modern alternators. Here we note that the dc exciter is supplying current to the loop by means of brushes and slip rings. The pole pieces have coils wound from a continuous length of wire. The ends of the wire are connected to conductors which carry the alternating current to the transformer and to the transmission lines. As the loop is rotated by the prime mover, the magnetic field sweeps across the pole pieces and by magnetic induction produces a voltage which causes current to flow through the coils and conductors. Since the magnetic field has polarity, the induced current flows in the opposite direction every half-revolution.

One of the major advantages of this type of alternator over the rotating-armature type pertains to the amount of current carried by the brushes and slip rings. Slip rings are exposed; they are subject to arc-overs and short circuits when they are required to carry high voltage and current. Because the rotating-field type of alternator can generate exceptionally high voltage and current from the magnetism produced by relatively low voltage from the dc exciter, arc-overs and short circuits at the slip rings are avoided.

In an actual alternator, the stator has many slots and pole pieces around which the continuous length of wire is wound. The manner of winding and the placement of the many coils is too complex for illustration and is too involved for explanation in this course. For this reason only a schematic of the windings and their relationship to the rotating magnet is shown in Fig. 3-20. The loops represent the continuous length

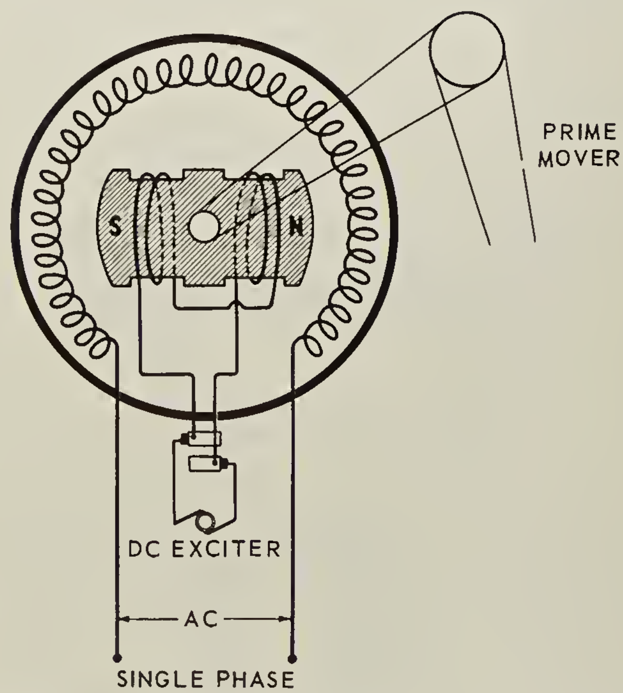


Figure 3-20. An ac single-phase alternator (schematic diagram).

of wire imbedded around the entire circumference of the stator. The rotating magnetic field is produced by a rotating electromagnet driven by the prime mover. The electromagnet is produced by the exciter-fed coils of wire wound around the metal core. The slip rings permit the electromagnet to revolve without changing the polarity of the core. The number of pole pieces required in the electromagnet is dependent on the speed of the prime mover; the slower the speed, the greater the number of poles will be required to produce the same frequency of current as a two-pole core would produce at higher speeds.

Just as electromagnetism plays a significant role in the generation of voltage and current, so does it play an equally important role in their transmission and utilization. The next chapter is devoted to these two subjects.

Power—transmission and transformers

CHAPTER

4

In the preceding chapter, reference was made to power companies and power plants. The word "power" brings to mind such terms as energy, strength, force, and work. We next ask what voltage and current have to do with power. As we learned earlier in the book, electromotive force is used to overcome the resistance of a circuit, and the total voltage in the circuit is the sum of all voltage drops. We learned also that the amount of current returning to a source of electricity is the same as that leaving it. Voltage and current in combination are capable of producing electric energy.

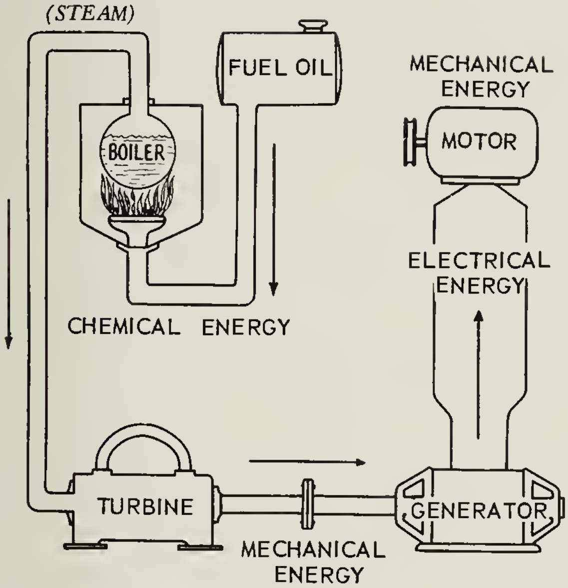


Figure 4-1. Conversion of energy.

Figure 4-1 points up the fact that energy can be converted from one form to another. For example, the heat energy stored in fuels can be converted by chemical action to mechanical energy to drive a turbine. The turbine, in turn, converts the mechanical energy to electric energy. The electric energy can then be converted to mechanical energy to produce work. All these forms of energy are closely associated with heat.

BASIC NOTIONS IN POWER PRODUCTION

In the preceding chapter we dealt with the conversion of mechanical energy to electric energy. In this chapter we are concerned primarily with the conversion of electric energy to mechanical energy or, in other words, how voltage and current can be combined to produce power. To understand power, a knowledge of force and work is required.

Force

On numerous occasions during our discussion we have used the word "force" in describing the pressure of an electric current. There are many kinds of force. When you move or lift something, you use force. Every time anything is moved or tends to be moved, force has been exerted. There also is the force of gravity, which causes bodies to move toward the earth; mechanical force, such as that exerted by a propeller; and chemical force, such as that exerted when oxygen and hydrogen are united to form water.

In Fig. 4-2, a 55-lb weight is fastened to a rope and pulley, and a small child is pulling on the rope with all his might without being able to lift the weight from the floor. Force is being exerted, but no work is being done.

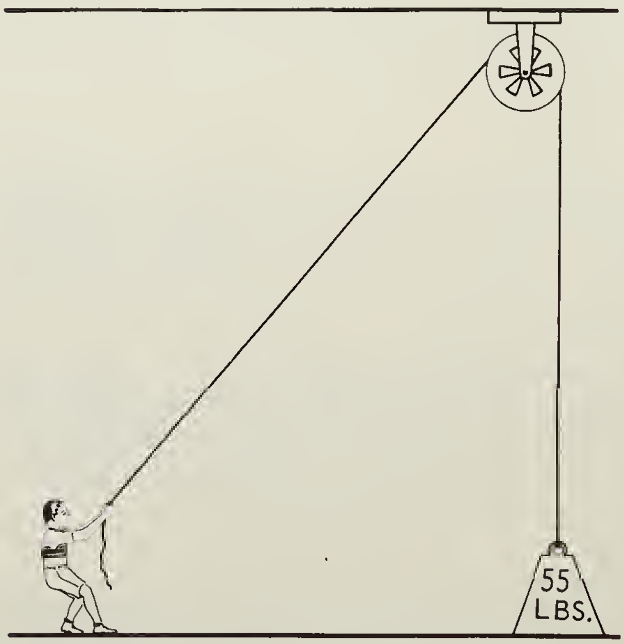


Figure 4-2. Force being applied, but no work.

Work

One of the fundamental units of measure which applies to electricity, as well as to other forms of energy, is the *unit of work.*

Work is force acting through distance, or force *times* distance. For example, suppose a man pulls on the rope and exerts force to raise the 55-lb weight 10 ft from the floor as illustrated in Fig. 4-3. Work has been done because the force has been applied through space or distance. The

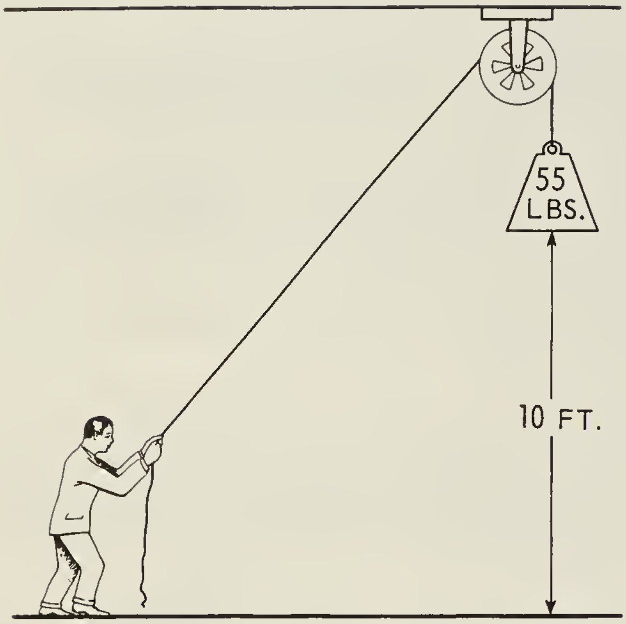


Figure 4-3. An example of work; work = force × distance (10 × 55 = 550 ft. lb).

man exerted a 55-lb force through a distance of 10 ft. The unit of work is measured in foot-pounds (ft-lb). So in this case, since *work = force × distance*, the man has done 55 × 10 = 550 ft-lb of work.

In electricity, the unit of work is the *joule*, abbreviated J. The joule by itself has very little use because it does not take into consideration the amount of time required to do the work.

Power

Power is the time rate, or speed, of doing work. This can be expressed by *power* equals *work* divided by *time*. The faster work is done, the greater the power required to do it. For example, when the 55-lb weight was raised 10 ft, 550 ft-lb of work was done regardless of whether it took 10 s or 10 min. However, it would take a lot more power to do it in 10 s than in 10 min. A steam shovel or a horse has more power than a man because either can do more work in a shorter period of time.

Units of Measure

Horsepower. As illustrated in Fig. 4-4, the common measure of power is the *horsepower* (hp). James Watt, who developed the steam engine, wanted a unit to compare the work done by his engines, in pumping water out of mines, with that done by horse-operated pumps. After a series of careful measurements, he established that a horse could lift 550 lb at the rate of 1 ft/s. This rate of doing work, 550 ft-lb/s, is termed a horsepower.

Watt. In an electrical system, as was stated in Chap. 1, the *watt* (W) is the unit of measure of electric power or the rate of doing work. 1 W of power is required to do 1 J of work in 1 s. But, since electric circuits are referred to in terms of voltage, amperage, and wattage rather than in units of joules, an equation which expresses the power in watts in terms of volts and amperes rather than in joules per second was devised and reads as follows: When an ampere of current flows between two points which have a difference of potential of 1 V, 1 W of power is being expended between the two points. Thus, the power expended in any circuit is the product of the voltage and the current flowing in that circuit. Expressed as an equation,

$$P = E \times I \qquad \text{or} \qquad E = \frac{P}{I} \qquad \text{or} \qquad I = \frac{P}{E}$$

where P = power, in watts
I = current, in amperes
E = potential difference, in volts

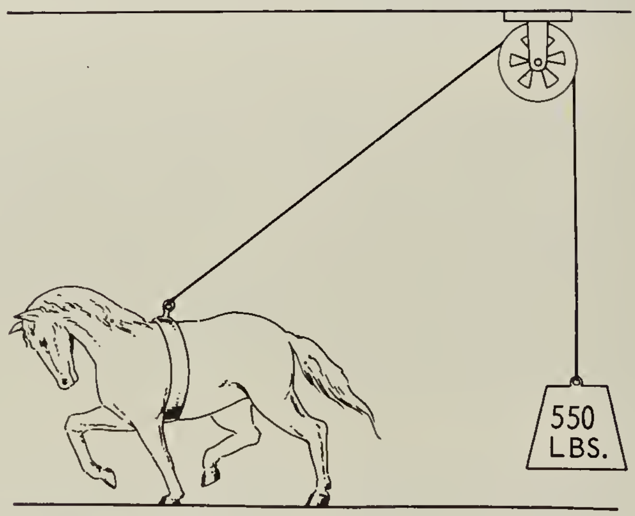


Figure 4-4. One horsepower of work; horsepower = 550ft-lb/s.

This formula is usually remembered as

$$\text{watts} = \text{volts} \times \text{amperes}$$

Since the watt is a very small unit of power, we commonly use the kW (kilowatt), which is 1,000 W:

$$\text{Kilowatt} = \frac{\text{volts} \times \text{amperes}}{1{,}000}$$

Any electric load, such as a light bulb, motor, toaster, radio, etc., consumes power (watts). For many years the term "consume" has been used to express the utilization of voltage and current. In keeping with this practice, the use of the term will be continued in this book. Most current-consuming devices are marked with the watts which they consume at a definite voltage. For this reason, the power company that furnishes current to your home charges you according to the number of watthours consumed over a month's period of time.

In electricity, the term "horsepower" is usually associated with electric motors. By measuring the amount of mechanical work a motor does in 1 s, it was determined that 1 hp equals 746 W. This is the mechanical power which is actually delivered as output. However, to obtain this amount of mechanical output or work, considerably more electric power must be consumed because of the heat and frictional losses within the motor.

Computing wattage. Figure 4-5 illustrates two methods of connecting meters in a circuit for the purpose of measuring current and voltage.

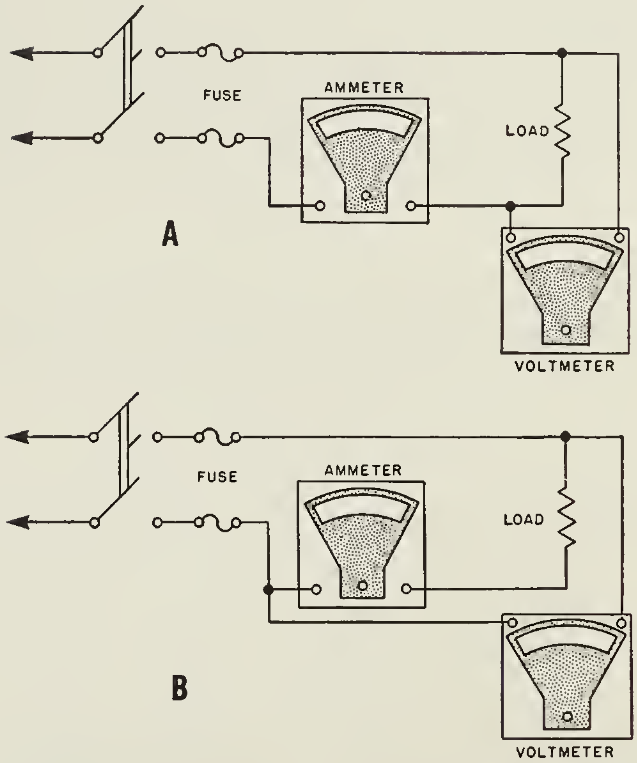


Figure 4-5. Measurement of current and voltage. (A) Best method of connecting meters when current is large. (B) Best method of connecting meters when current is very small.

Examples:

(1) If an electric motor requires 10 A at 110 V, what is the power consumed?

$$P = E \times I = 10 \times 110 = 1{,}100 \text{ W}$$

or $\qquad 1.1 \text{ kW}$

(2) If a battery charger operates at 100 V and consumes 600 W, what must be the smallest fuse which will maintain operation?

$$I = \frac{P}{E} = \frac{600}{100} = 6\text{-A fuse}$$

(3) What voltage will be measured at the terminals of a 500-W generator when 10 A are being drawn?

$$E = \frac{P}{I} = \frac{500}{10} = 50 \text{ V}$$

By the use of these power formulas, one of the three quantities of current, power, or voltage can be found if the other two quantities are known. Power also may be referred to in terms of resistance, and may be computed by substituting the Ohm's law value of resistance in the power formula,

$$P = E \times I \qquad I = \frac{E}{R} \qquad P = \frac{E \times E}{R} \qquad P = \frac{E^2}{R}$$

The latter formula also may be transposed as

$$E = \sqrt{PR} \qquad \text{or} \qquad R = \frac{E^2}{P}$$

The following examples will serve to illustrate the applieation of these formulas.

Examples:

(1) A resistor radiates 20 W of power in the form of heat when connected to a 20-V dc source. What is the resistance value of the resistor?

$$R = \frac{E^2}{P} = \frac{400}{20} = 20\ \Omega$$

(2) What is the wattage rating of a 120-V bulb which has a resistance of 144 Ω?

$$R = \frac{E^2}{R} = \frac{(120)^2}{144} = 100\ \text{W}$$

(3) What is the resistance of an electric iron which operates on 120 V and consumes 1,000 W?

$$R = \frac{E^2}{P} = \frac{(120)^2}{1{,}000} = \frac{14{,}400}{1{,}000} = 14.4\ \Omega$$

Since power is the time rate of doing work, it follows that the greater the length of time the power is consumed, the greater will be the total amount of power consumed. Electric power is purchased commercially in watthours (watts × hours) or kilowatthours [(watts × hours)/1,000]. A 100-W lamp requires 100 W of power for proper operation and consumes 100 Wh of power in 1 h, 200 Wh in 2 h, etc. In terms of kWh, the lamp uses 100/1,000 = 0.1 kWh of power in 1 h; in 10 h, the lamp uses 10 times as much, or 1 kWh of power.

Examples:

(1) A kWh meter reads 0.09 kW in 10 h. What is the average rate of consumption?

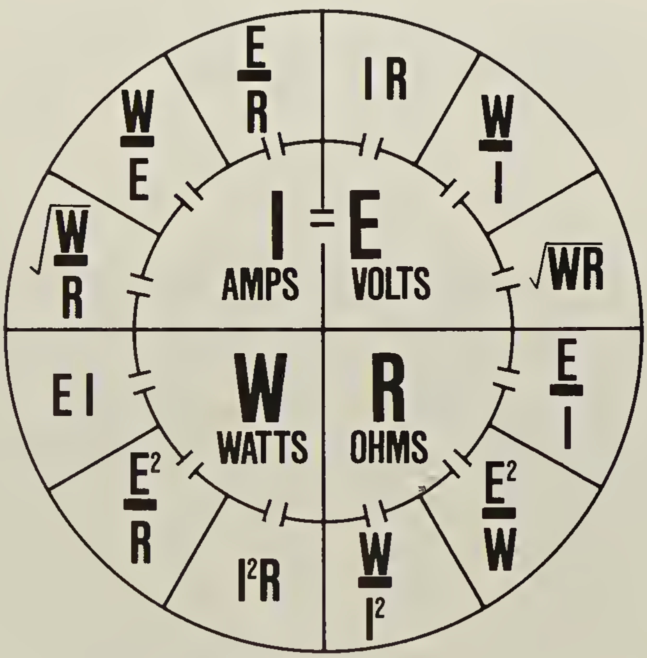
$$0.09\ \text{kW} = 90\ \text{W}$$
$$\tfrac{90}{10} = 9\ \text{W/h}$$

(2) If a 2-hp motor is connected to the power line and operated for 10 h continuously, what will be the power consumed in kWh?

$$746\ \text{W} = 1\ \text{hp}$$
$$1{,}492\ \text{W} = 1.492\ \text{kW}$$
$$1.492\ \text{kW} \times 10\ \text{h} = 14.92\ \text{kWh}$$

Formulas and equations are difficult for the average person to remember. A simple method of computing Ohm's law and the power equation is shown in Fig. 4-6. To use this "memory circle of formulas" for finding amperes, volts, ohms, or watts, you must have any two of the others. The quantity to be found is located in a quadrant of the inner circle. Use the two known quantities as indicated in the outer circle in its quadrant.

Electrical unit prefixes. The simple units of electrical measure—volts, amperes, ohms, and watts—are rather clumsy when very large or very small quantities are involved. Therefore, a system of electrical unit prefixes is used to indicate large and small quantities. They are *kilo* (k), *milli* (m), *mega* (M), and *micro* (μ). For example, as mentioned earlier in this chapter, a generator which delivers 1,000 watts is called a 1 kW generator. Instead of saying the flow of current is one-thousandth ($\frac{1}{1{,}000}$) of a volt, we say it is 1 mV. If we are testing insulation, we might say it has a resistance of 1 MΩ instead of 1 million ohms. The term *farad* (F) is used as a unit of measure for electric capacity; but



W=Power or **Watts**
I=Intensity or **Amps**
R=Resistance
E=Electro Motive Force or **Volts**

Figure 4-6. Memory circle for formulas using Ohm's and Watt's laws.

the farad is very large, and so the capacity of capacitors is given in μF, or so many millionths of a farad.

Having established certain fundamental facts pertaining to the production of electric energy or power, and having discussed electrical units of measure, let us now take a look at the various aspects of the transmission and utilization of electricity.

Power Losses

All appliances and motors lose some power; otherwisc they would be 100 percent efficient, a situation never encountered in practice. The most common loss of electric power is the power which is dissipated in the form of heat when current flows through a resistance. This power loss is sometimes called the I^2R *loss* or *copper loss*, and is always present when current is flowing. The heat is usually dissipated into the air and lost, but it may be utilized, as in the case of the electric oven, toaster, soldering iron, or filament of a light bulb. The power loss may be calculated by the following formula:

$$P = I^2R \qquad \text{or} \qquad P = \frac{E^2}{R}$$

Electric motors have losses due both to friction and to resistance of the windings. Therefore, the mechanical output can never equal the electric input. The output of any power-consuming device divided by the input and multiplied by 100 will give its power efficiency in percent:

$$\%\ \text{efficiency} = \frac{\text{output}}{\text{input}} \times 100$$

Examples:

(1) If a 1-hp motor draws 6 A of current at 220 V, what is the efficiency of the motor?

$$\text{efficiency} = \frac{\text{output}}{\text{input}} \times 100$$

$$= \frac{746}{220 \times 6}\ \text{W} \times 100$$

$$= \frac{74{,}600}{1{,}320} = 56.51\%$$

(2) A certain tube when operating in a circuit draws 20 mA of current at 150 V. How much power is used?

$$20\ \text{mA} = 0.02\ \text{A}$$

$$P = E \times I$$

$$P = 150 \times 0.02 = 3\ \text{W}$$

(3) If 45 kW is supplied to a motor and its output is found to be 50 hp, what is the efficiency of the motor?

$$45\ \text{kW} = 45{,}000\ \text{W} = \text{input}$$

$$50\ \text{hp} = 50 \times 746 = 37{,}300\ \text{W} = \text{output}$$

$$\text{efficiency} = \frac{\text{output}}{\text{input}} \times 100$$

$$= \frac{37{,}300}{45{,}000} \times 100 = 83\%$$

Power Factor

Since the introduction of fluorescent lights and the mass production of motor-powered refrigeration systems and appliances, the term *power factor* has come into fairly common use. Before entering into this discussion we should not confuse the power factor with the efficiency of an electrical device.

A complete coverage of the subject of power factor is beyond the scope of this book. For our purpose, it may be defined as the difference between the amount of power supplied by the power company for a device and the amount of power consumed by this device for which the company receives no payment. To understand how such a condition can exist, we must take into consideration that, except for capacitors, there are two classifications of current-consuming devices or loads: those called "*pure*" *resistance type* and those called *induction type*. Pure resistance loads include incandescent lights and all types of heater elements.

Induction-type devices are those which have coils of wire wound around metal cores and in which electromagnetism is produced during operation. Induction-type devices include transformers, ac motors, relays, solenoid valves, and fluorescent-light equipment. Figure 4-7 is an

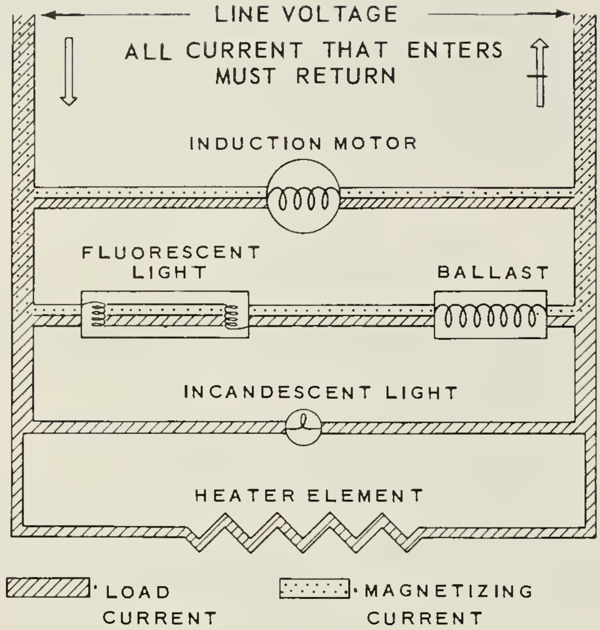


Figure 4-7. Distribution of current in a circuit (resistance vs. inductance).

attempt to illustrate how current is distributed in a total parallel circuit containing both pure resistance and induction-type loads or devices. In fact, many dryers incorporate such a circuit. The induction motor turns the drum, the fluorescent light illuminates the top, the incandescent light illuminates the interior, and the heater element dries the clothes. The basic construction and operation of induction motors and fluorescent-light equipment will be discussed later in the book.

It should be remembered that the rate of current flow returning to the source is the same as that entering a circuit from the source. The power company is quite concerned about the way the current they provide and get back has been utilized. Pure resistance loads have no metal cores requiring magnetism. Therefore, the power company's meter records all the energy consumed by such devices. In these instances, the power factor is said to be 100 percent.

With the induction-type loads, however, some of the current supplied by the power company is used only to magnetize the metal core, while the remaining current overcomes resistance and performs the work. Magnetizing current does no work and, therefore, it is not recorded on the power company's meter. If one-fourth of the current being supplied to an induction-type device is required to magnetize the metal and only three-fourths of it is used to produce work, the device is said to have a 75 percent power factor. The 25 percent is a direct loss to the power company due to the fact that they have spent money for fuel and equipment to supply current through resistance of lines, transformers, etc., for which they receive no payment.

Realizing that induction-type devices are essential to our way of living and that some current losses are unavoidable, power companies have established a minimum of 90 percent power factor as that being acceptable for devices connected to their power lines. Power factor can also be expressed in decimals, but it is usually expressed as a percentage.

To further our discussion of power factor and how it can be computed, a simple circuit is illustrated in Fig. 4-8. Except for the meters, the only resistance involved is a heater element, which, as previously mentioned, is a pure resistance. For the sake of simplicity, the voltages and currents utilized by the meters are ignored.

We note that the heater has a resistance of 10 Ω; the voltage (E) is 100 V and the heater is

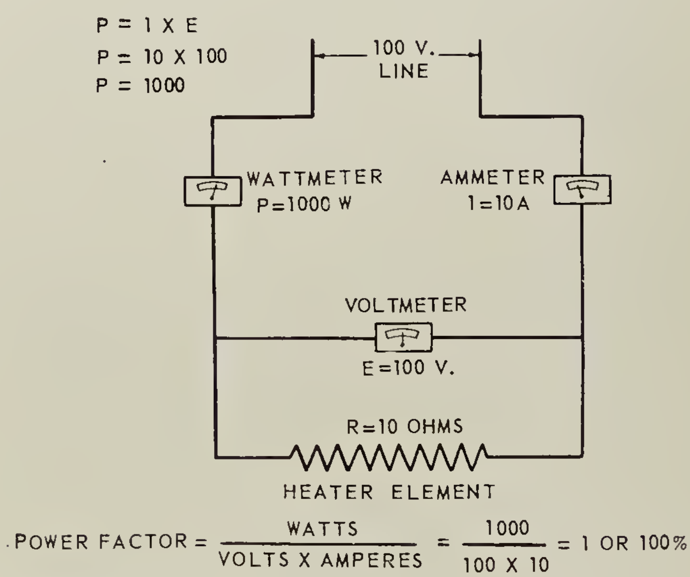


Figure 4-8. Computing power factor (pure resistance circuit).

drawing 10 A of current (I). Applying the power equation, $P = I \times E$, we find that the heater is consuming 1,000 W. The wattmeter has a voltage coil and current coil in parallel which, in effect, multiplies the two factors and records the answer on the dial. In all instances, the power factor is watts/volts × amperes, or $1{,}000/(100 \times 10) = 1$, or 100 percent.

Computing the power factor for induction-type loads becomes more complex and will not be discussed in this book. From the foregoing we can conclude that home and small-business owners are not concerned with power factor. Industrial plants, however, which use large quantities of induction-type equipment receive special rates from power companies when the plants install banks of power-factor-correction devices. To provide corrective measures for magnetizing-current losses incurred in homes and business establishments, most power companies install their own power-factor-correction equipment in the power plant.

Most manufacturers of modern induction-type devices attempt to cooperate with power companies either by designing their products with as high a power factor as economics permit or by including, as part of the equipment, a corrective device. How magnetizing or wattless current can be reduced, and the power factor increased, on motors and fluorescent-lighting equipment will be discussed later in the course.

INDUCTANCE

Inductance is the characteristic of an electric circuit which opposes the starting, stopping, or changing of current flow. The above statement is of such importance to the study of inductance that it bears repeating in a simplified form. Inductance is the characteristic of an electric conductor which opposes a change in current flow.

One does not have to look far to find a physical analogy of inductance. Anyone who has ever had to push a heavy load (wheelbarrow, car, etc.) is aware that it takes more work to start the load moving than it does to keep it moving. This is because the load possesses the property of *inertia*. Inertia is the characteristic of mass which opposes a change in velocity. Therefore, inertia can hinder us in some ways and help us in others. Inductance exhibits the same effect on the current in an electric circuit as inertia does on the velocity of a mechanical object. The effects of inductance are sometimes desirable and sometimes undesirable.

On September 22, 1791, in Newington Butts, London, a man was born who was destined to play a great part in the laying of the foundation of the growing science of electricity. This man, Michael Faraday, started to experiment with electricity around the year 1805 while working as an apprentice bookbinder. In 1831 Faraday performed experiments on magnetically coupled coils. A voltage was induced in one of the coils due to a magnetic field created by current flow in the other coil. From this experiment came the induction coil, the theory of which eventually made possible many of our modern conveniences such as the ignition coil in the automobile, the doorbell, the auto radio, etc. In performing this experiment Faraday also invented the first transformer, but since alternating current had not yet been discovered, the transformer had few practical applications. Two months later Faraday constructed, on the basis of his experiments, the first direct-current generator. At the same time that Faraday was doing his work in England, Joseph Henry was working independently along the same lines in New York. The discovery of the property of self-induction of a coil was actually made by Henry a little in advance of Faraday, and so the unit of inductance is called the *henry*.

Self-Induction (Counter-emf)

In the previous chapter it was pointed out that a flow of current through a solenoid coil produces a magnetic field of flux which changes polarity as the direction of current changes. It was also pointed out that a moving magnetic

field produces a voltage and a current in a conductor. The question is, why are voltage and current not produced in a solenoid coil connected to a source of alternating current? The reason for this is an effect which is called *self-induction.* There is a law of physics which states that for every force there is an equal and opposing force. Whenever alternating voltage and current flow through a solenoid coil, each cycle produces an alternately expanding and contracting magnetic field of flux over the adjacent loops of wire in the coil. This induces a voltage in the coil which opposes the applied voltage and current. This voltage is known as *counter-emf,* and its value is always less than that of the applied voltage.

In Fig. 4-9 the large white arrows at each end of the coil indicate the direction of the applied voltage. The small black arrows indicate the direction of the counter-emf (induced voltage). Figure 4-9A illustrates the relation between the voltages during the first quarter-cycle, when the applied voltage is trying to build up. The counter-emf opposes its buildup. Figure 4-9B illustrates the second quarter-cycle, when the

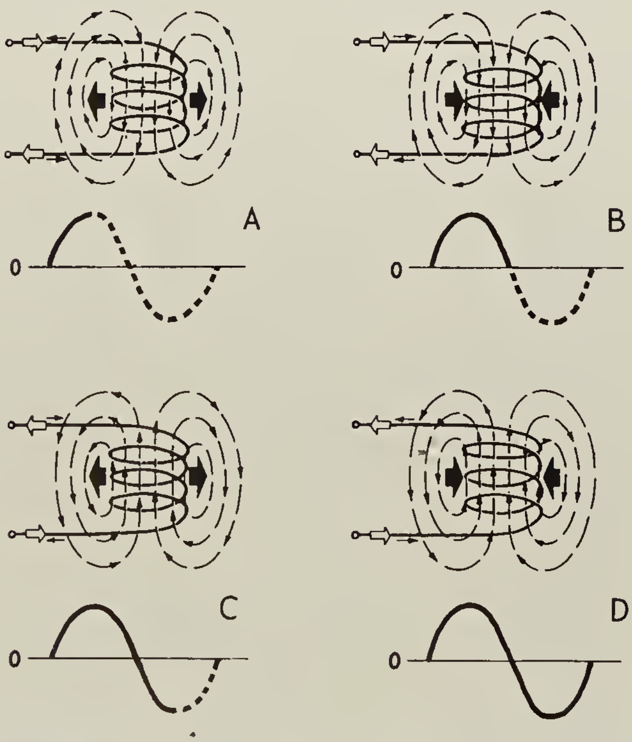


Figure 4-9. The action of self-induction (counter-emf).

applied voltage is dropping back to zero. The counter-emf now is working in the same direction as the applied voltage and is opposing the drop in applied voltage. Figures 4-9C and 4-9D likewise illustrate that the counter-emf is always opposing changes in the applied voltage. The current flow resulting from the inner action of these opposing forces is smaller than it would otherwise be. Actually, the counter-emf controls and regulates the amount of current through the coil, thus preventing the coil from overheating and burning. It is also interesting to note that because of the opposition between the applied and induced voltage, the resulting flow of current is slightly delayed so that its changes lag behind the changes in the applied voltage. This lag of current behind voltage introduces a timing factor which is utilized in the operation of self-starting electric motors.

Mutual Induction

The word "mutual" means "sharing." Many years ago it was discovered that a solenoid coil, by induction, could share its current and voltage with another coil of wire connected only to a load. In other words, if a coil of wire is connected to a source of current, current will flow also through an adjacent coil of wire connected only to a load.

The principle of mutual induction can be readily demonstrated and explained with the equipment illustrated in Fig. 4-10. The coil connected to the switch and to the battery is called the *primary coil.* The adjacent coil, which is connected only to the galvanometer, is called the *secondary coil.* The galvanometer represents the load.

The iron core around which the coils are wound is not essential to the principle of mutual induction, it merely provides a stronger field. Mutual currents and voltage can be induced also across an air gap.

When the switch is closed, the primary coil and core together become a magnet. The buildup of magnetic flux cutting across the coils of the secondary causes current to flow through the secondary coil and circuit as indicated by

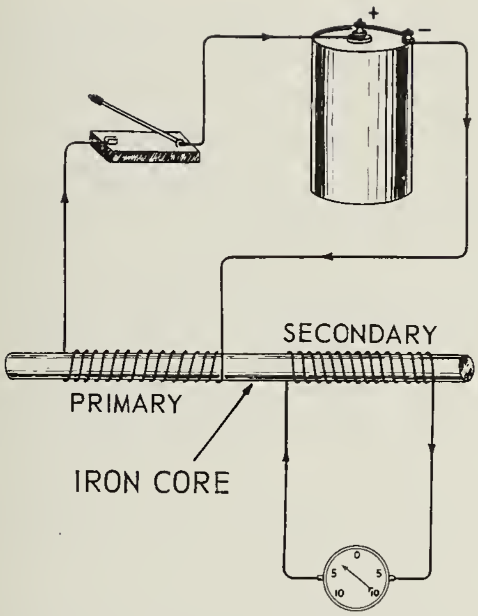


Figure 4-10. The principle of mutual induction.

the galvanometer. The flow of current in the secondary, however, is only during the instant that the magnetic field is formed. When the switch is opened, the core demagnetizes instantly, and the collapse of the magnetic flux causes current to flow in the opposite direction. From this it can be concluded that mutual induction depends entirely upon the alternate expanding and collapsing of the magnetic field around adjacent coils of wire. With direct current, this is accomplished by rapidly making and breaking the circuit; with alternating current, the same effect is produced by rapid changes in magnetic flux as the current alternates.

When used with alternating current this device is called a *transformer*. A transformer is unique in that it can remain connected to an ac supply and almost no current will flow in its primary as long as its secondary circuit is opened. The reason for this is that the self-induction which takes place in the primary produces a counter-voltage which is almost equal to the applied voltage. Almost no current results from these opposing voltages. When the secondary circuit is closed, however, a current is induced in the secondary coil. This produces magnetism which is opposite in polarity to that produced in the primary. This reduces the counter-voltage produced in the primary by self-induction and allows a current to flow in the primary. Only because of alternating current is a transformer made possible, and only because of transformers is modern transmission of alternating current possible.

TRANSFORMERS

The transmission and utilization of voltage and current cannot be understood without first having at least a basic knowledge of transformers. As previously stated, only because of transformers is it possible to transmit alternating current over long distances at a reasonable cost. There are also many other applications in which transformers play a significant role in the operation of equipment. Because of the many uses to which they can be put, transformers are manufactured in hundreds of sizes, shapes, and current characteristics. They range in size from several tons in weight, for transmission purposes, to a few ounces for radio and television sets. Regardless of their size or shape, however, they all have the same basic components and function on the same basic principles—self-induction and mutual induction.

Construction of a Transformer

A common type of transformer construction consists of two separate windings of insulated wire wound around an iron core. One winding is known as the *primary winding* and the other as the *secondary winding*. The primary winding of a transformer receives energy from an ac voltage source. Changing magnetic lines of flux are set up by the changing current flowing through the primary. The changing current in the primary winding causes an electromagnetic field to build up and collapse. This field cuts through the secondary-coil winding and induces a voltage in the secondary. In this way the electric energy is transferred from the primary to the secondary

by induction. Notice that the frequency of the electromagnetic waves does not change as the power is transferred from the primary to the secondary windings.

This fluctuating magnetic energy produced by the primary current is efficiently coupled to the secondary coil by means of a laminated steel core. The efficiency with which the magnetic energy is coupled is primarily due to the good permeability (magnetic conductivity) of the steel core. The efficiency of a transformer core can be increased by using a core with a greater permeability.

Transformers are designed to keep power loss at a minimum. One of the principal unavoidable losses is the *iron loss.* Iron losses occur in the core and result from two factors, *hysteresis* and *eddy currents.* Hysteresis loss is caused by the resistance that the molecules of the iron offer to being shifted each time the alternating current is reversed. (The molecules of the core are shifted 120 times each second in a 60-Hz transformer.) The resistance to this shifting is the result of friction, and the friction produces heat. Losses from hysteresis cannot be eliminated; however, they may be reduced considerably by the use of soft steel or a special transformer steel containing silicon. The molecules of these metals shift more easily, produce less friction, and result in a minimum iron loss due to heat.

There is another type of power loss in transformers. If transformer cores were made of solid steel, as shown here in Fig. 4-11A, the alternating magnetic flux produced by the transformer primary winding would induce currents in the transformer core. These are called eddy currents because they eddy, or circulate, entirely within the iron core and are really short-circuited currents flowing within the core material. They produce heat for the same reason that any short-circuited current produces heat. A current of electricity will be produced in a conductor, such as in the cross section of steel core shown in Fig. 4-11A, whenever an alternating magnetic flux is passing through it. This, of course, would be the case if the conductor were a part of the core structure of a transformer. Eddy currents may be broken up by slicing the core into thin sections and insulating them from each other, as shown in Fig. 4-11B. Small eddy currents will still flow in the sliced sections. Eddy currents cannot be entirely eliminated, but they can be reduced to a point where the loss is negligible if the laminations are very thin.

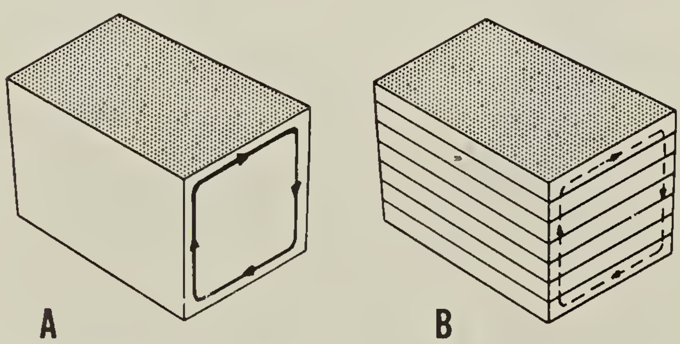


Figure 4-11. (A) Eddy currents are set up in a solid steel transformer core through which alternating magnetic lines of force are passing. (B) Slicing (laminating) a steel transformer core into thin sheets reduces the eddy currents considerably.

The *transformer core loss* and the *copper loss* in the transformer are converted to heat. Unless there is some means provided for continuously removing the heat from the case and windings, they would get progressively hotter and eventually result in failure due to overheating.

In the oil-filled transformer, the oil is used, in addition to its insulating qualities, as a medium for carrying off the heat in the core and coil section to the tank wall. The tank wall then dissipates this heat to the surrounding air, and a heat balance is maintained. The transformer core and windings are placed in an oil bath in a tank nearly filled with oil, allowing a space above the oil to take care of any change in its volume. The oil is circulated through the heated parts of the transformer.

As the oil is heated, it expands, so that its weight per gallon is reduced; i.e., 1 gal of heated oil weighs less than 1 gal of cooled oil. This action causes the heated or expanded oil to rise vertically through the cooling ducts. This rising oil results in a downward column of oil coming in contact with the inside of the tank wall. The tank wall then dissipates the heat carried by the oil to the surrounding air. The oil is cooled,

becomes heavier, and assists in setting up the circulating circuit.

Theory of Operation

Since a transformer operates on the principle of induction, caused by changing currents flowing through the windings, it will not operate if pure direct current is applied to the primary coil. When direct current of a fluctuating nature is applied, the fluctuation causes a transfer of energy from the primary to the secondary. The current in the primary coil of a transformer must be interrupted or varied. For this reason transformers are generally used with alternating current.

Since the current in the primary coil of a transformer is constantly changing in value, it follows that the magnetic flux in the core is also constantly changing. The magnetic flux and its polarity are dependent upon the current flowing in the primary coil. As the direction of the current in the primary coil changes, the direction of the magnetic flux also changes.

It should be remembered that the polarity of the voltage induced in the secondary coil of the transformer depends upon the direction the magnetic field is moving. The magnetic field builds up to a maximum and falls to zero; then it reverses and builds up to a maximum in the opposite direction and again falls to zero. The voltage in the secondary coil will build up, then fall off and reverse, just as the voltage in the primary coil does. The polarity of the voltage induced in the secondary coil will be opposite to the direction of the current in the primary coil if the primary coil and the secondary coil are wound in the same direction.

The strength of a magnetic field produced in a coil will be directly proportional to its ampere turns. One ampere of current will produce a certain number of lines of force in one turn of a coil. Either 2 A in one turn of a coil or 1 A in two turns of a coil will produce twice as many lines of force. You can see that the voltage induced in the secondary coil will depend upon the number of ampere turns of the primary coil and upon the number of turns in the secondary winding. This can be expressed by the equation:

$$\frac{E_P \text{ (primary volts)}}{E_S \text{ (secondary volts)}} = \frac{N_P \text{ (primary turns)}}{N_S \text{ (secondary turns)}}$$

A given number of ampere turns for the primary winding will cause a certain voltage to be induced in each turn of the secondary coil. Two turns of the secondary winding will induce twice that amount, three turns three times that amount, etc. This results from the fact that all the turns of the secondary coil are in series with each other. The total voltage is equal to the sum of all the individual voltages. A transformer having the same number of turns on the primary and secondary windings will have a voltage induced in the secondary winding equal to the voltage applied to the primary winding.

As you can see, the relationship or ratio between the number of turns in the two coils is nearly direct. For example, if the primary coil is connected to a source of 120-V current and it is desired to supply the load with 240 V, the secondary coil must have approximately *twice* the number of turns as the primary. This is called a *step-up transformer.* On the other hand, if the source is 240 V and the load requires only 120 V, the secondary coil must have

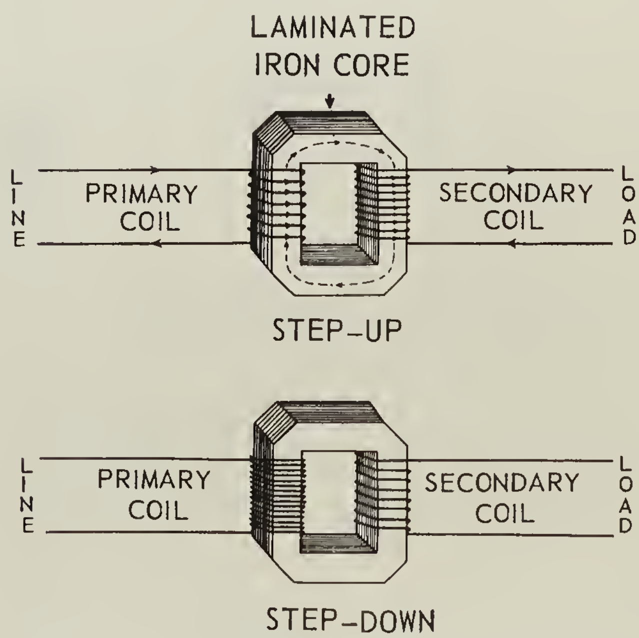


Figure 4-12. Two types of transformers.

approximately *half* the number of turns as the primary. This is called a *step-down transformer.*

The current in the secondary coil always changes by the inverse of the ratio by which the voltage changes. If the voltage is doubled, the current is halved. If the voltage is raised to 10 times its original value by the transformer, the current in the secondary coil will be reduced to one-tenth the value of the current in the primary coil. This means that the voltage in the primary winding is multiplied by the turns ratio to find the voltage in the secondary winding. To find the current in the secondary coil, divide the current in the primary coil by the turns ratio.

While a transformer can increase or decrease the voltage and current, it cannot generate energy. For example, if the voltage is stepped up from 120 to 240 V and the load requires 2 A and consumes 470 W, the primary coil must be designed to carry 4 A so that the wattage remains the same. In other words, it is impossible to get as much power out of a transformer as is put into it, because no device can be made to operate at 100 percent efficiency. There is always some loss. However, if we assume a transformer to be operating at an efficiency of 100 percent, the amount of transformed energy from the transformer is neither increased nor decreased. Only the ratio of the values of voltages and currents is changed.

The method of transferring electric energy by the transformer is indirect. It first converts the electric energy into magnetic energy; then it reconverts magnetic energy into electric energy. Because of this conversion process, the transformer can perform duties which have made it invaluable in the field of electrical science.

Uses of Transformers

With the basic principles of transformers in mind, let us briefly discuss some ways in which transformers are used.

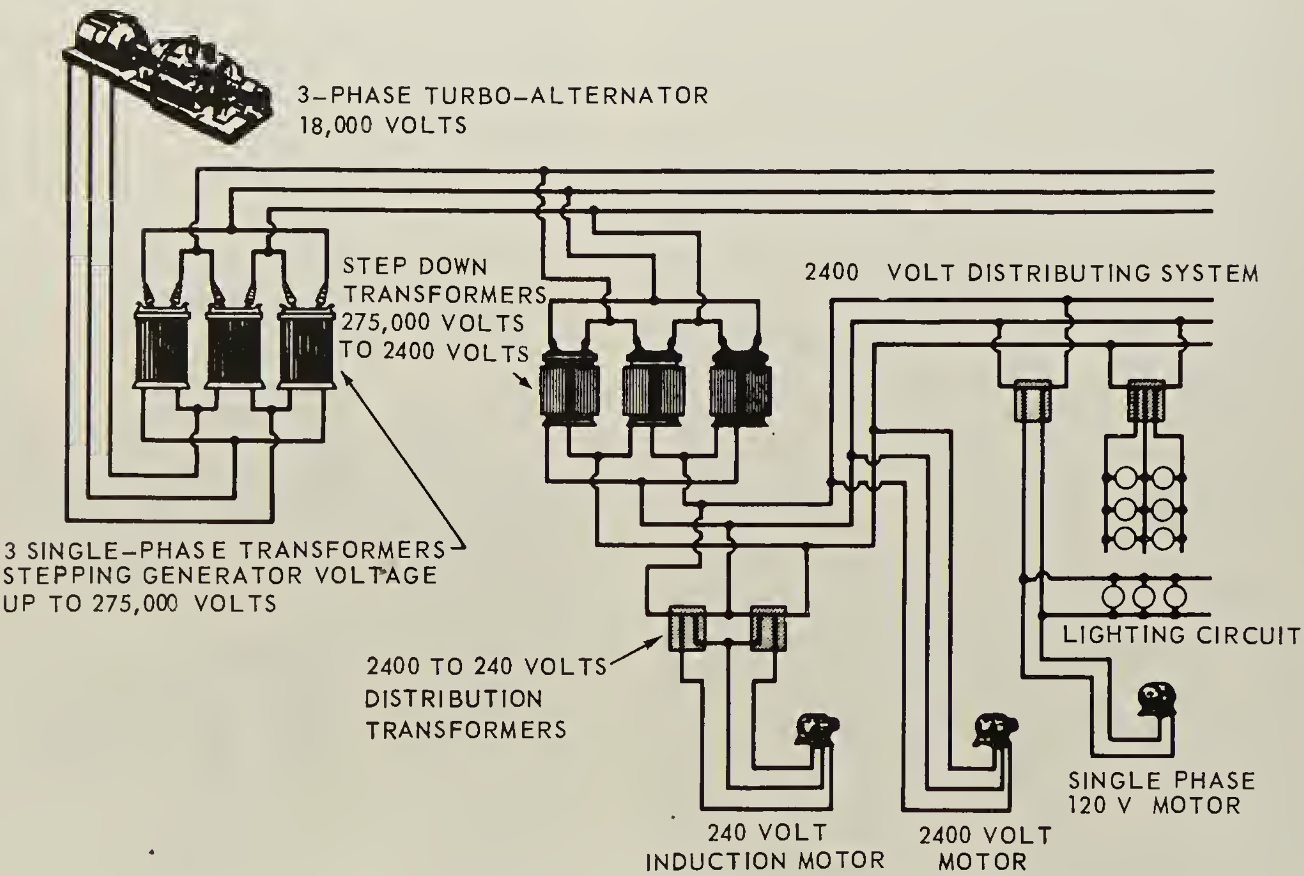


Figure 4-13. Transformers are used for many purposes in a power transmission and distribution system.

Transmission transformers. The most important uses of transformers is in the transmission of power. To illustrate the fact that alternating voltage and current can be transmitted over long distances, a typical network is shown in Fig. 4-13. In this instance the alternators in the power plant are generating a voltage of 18,000 V. The step-up transformers located outside the plant boost it to 275,000 V for transmission to one or more substations located several miles away. The transformers at the substation step the voltage down to 2,400 V for distribution to smaller transformers on utility poles scattered throughout a community. Let us assume that the home on the left requires 240-V current for operating an electric range, clothes dryer, or water heater, using a three-wire hookup. It also requires 120-V current for lights and small appliances designed for 120-V service. This can be accomplished by transformer taps that reduce the 2,400 V to 240 V through two of the wires and 120 V through the combination of the third (neutral) wire and either of the other wires. For homes not requiring 240-V service, a two-wire, 120-V service can be obtained from the same transformer. How the combination of voltage is obtained is illustrated in Fig. 4-14. The illustration also shows the symbol for a transformer when used in a schematic wiring diagram. We note that the transformer is being supplied with 2,400 V from the power company's substation. The secondary coil has two equal sections connected together. This is commonly referred to as a *center-tap connection.* The voltage has been stepped down to 240 V in the secondary coil, and the two outside leads can deliver 240-V service for equipment requiring that voltage. A lead from the center tap, called the neutral lead, can be used in combination with either of the outer leads to operate 120-V equipment. For example, for ranges and dryers a three-wire service is provided. This permits connecting the heater elements to a source of 240-V current while the motors, lights, timers, and other equipment designed for 118 to 120 V can readily be supplied with the lower voltage. Both the power

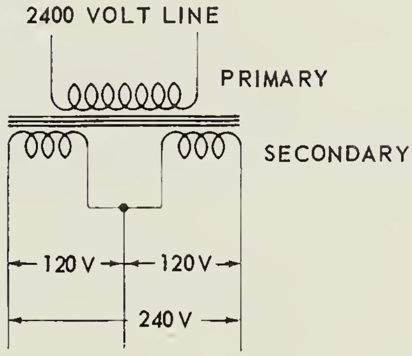


Figure 4-14. Schematic of three-wire transformer.

company and the manufacturer are concerned with the proper balancing of loads on three-wire service.

The question arises, who determines what voltages are to be supplied from the transformer on the pole? This is a mutual agreement between the power company and the manufacturers of electrical equipment. For many years the standard and accepted voltage for most components was 110/220 V. As communities grew and more electrical equipment was connected to the power lines, the need for higher voltage became greater. It was first increased to 115/230 V, then later to 118/236 V. At the present time, most voltages for homes and business establishments is supplied at 120/240 V. This does not mean that all appliances must be designed for this higher voltage. For example, many ranges are now designed for 118/236 V, while many clothes dryers are 120/240 V. It should be remembered that the design voltage of an appliance can be 3 to 5 V higher or lower than the line voltage without materially affecting its operation.

The voltages generated and transmitted to and from the substations can vary considerably from those shown in the figure. It depends upon the distances, and upon the number of consumers and their demands. Approximately 90 percent of the power generated and transmitted at the present time is relatively close to the voltages given.

It may be interesting to note the huge size and the external appearance of the transformers

located outside the power plant and at the substation. In most instances, they have external fins, which serve as heat-radiating surfaces, and they have external piping systems for circulating oil through the interior of the transformer for cooling purposes. This is required because of the exceptionally high amount of heat produced by the high current demands and the internal heat produced in the cores. The small transformers used on home appliances require no special cooling devices due to the relatively small amount of heat produced.

Appliance transformers. The transformers used currently on most appliances are the step-down type. For instance, on electric ranges incorporating the all-electric oven-temperature-control system, a 120- to 12-V step-down transformer is used to supply low voltage to the oven-control switch and sensor (Fig. 4-15). The use of low voltage with these controls permits lighter, more sensitive construction to attain more accurate temperature control. Certain models of ovens feature a roast thermometer system which, by means of a buzzer, informs the user when the roast is done. This entire system is designed for 12 V, which is obtained from a 120- to 12-V step-down transformer.

A step-down transformer also plays a significant role in the design and operation of ice cube makers. A schematic of the low-voltage circuit

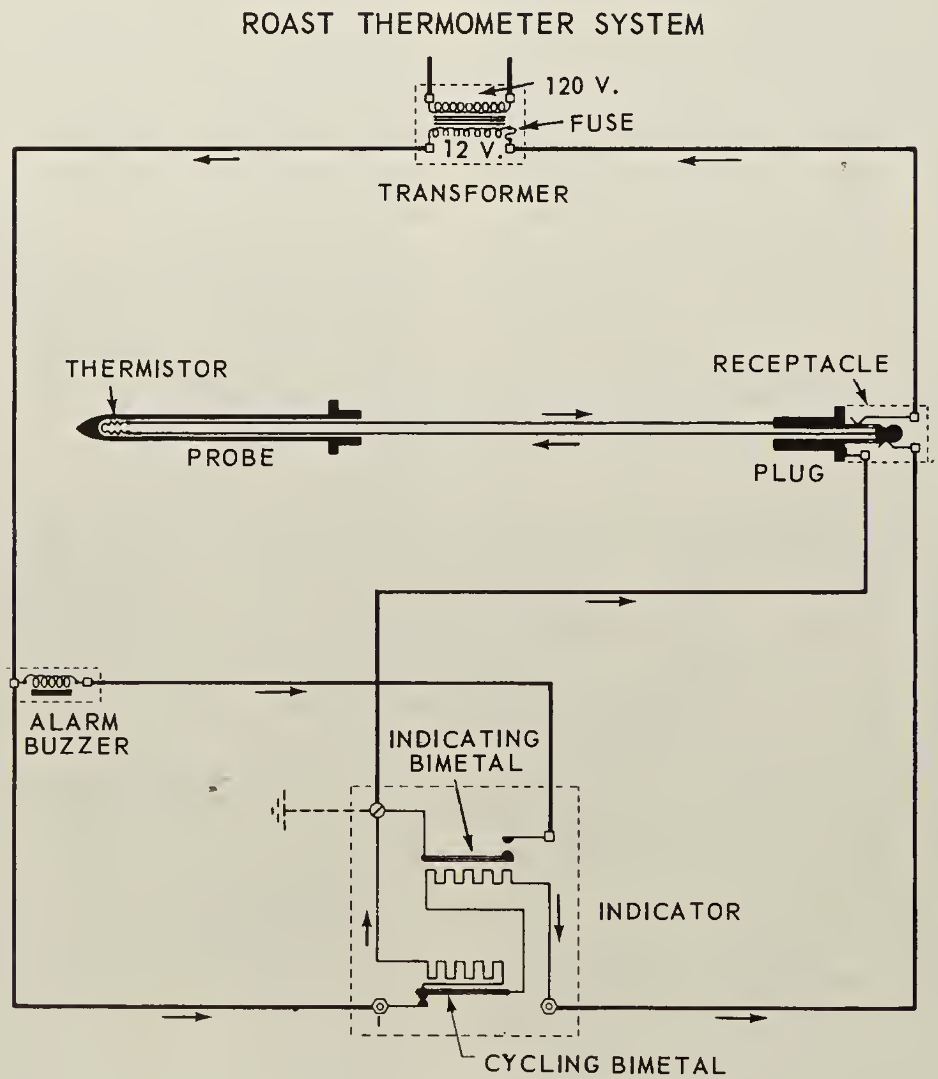


Figure 4-15. A roast thermometer system using a step-down-type transformer.

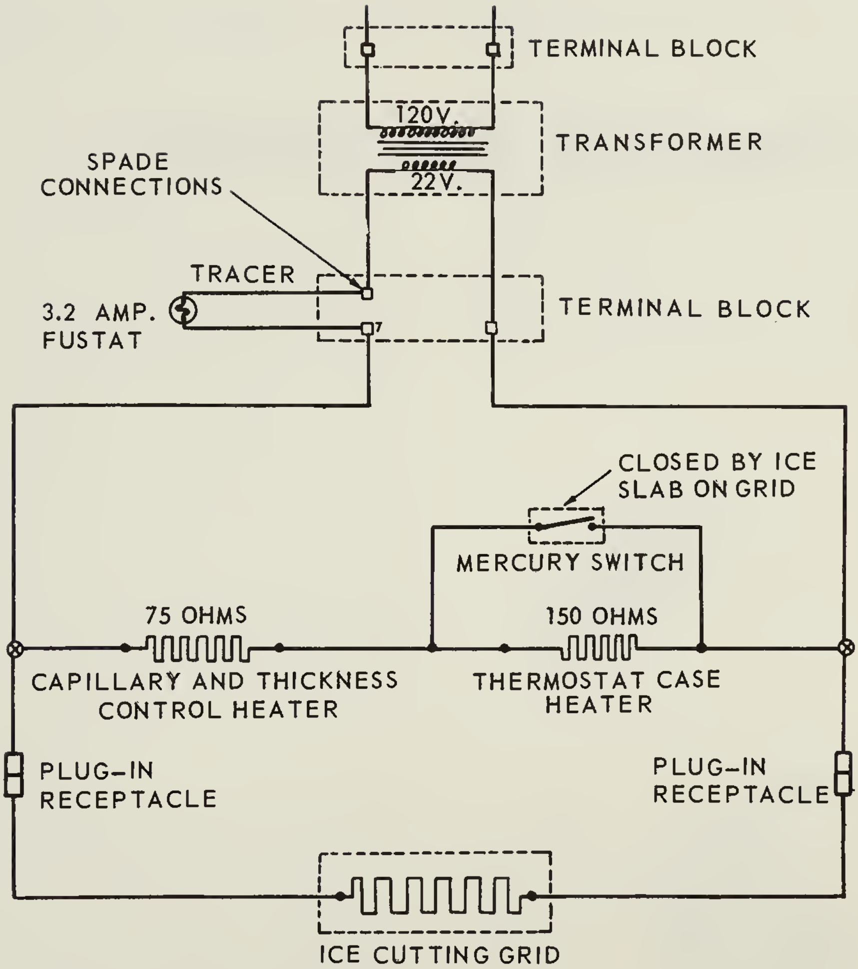


Figure 4-16. The low voltage portion of ice cube maker.

of such a transformer is shown in Fig. 4-16. In this instance the voltage is reduced from 120 to 22 V. From this it can be noted that the low voltage and current is provided for both the ice-thickness-control thermostat heaters and the ice-cutting grids. Briefly stated, the thermostat heaters reduce the OFF cycle after an ice slab has been released from the freezing plate, and the low current through the grids assists in cutting the slab into cubes with a minimum of melting. The two larger-capacity models use 14.25 V in the low-voltage circuit. The low voltage in all models is critical and essential to the proper production of ice cubes.

After the invention and development of the transformer it was discovered that the principles by which it operates could be incorporated into the design of motors that would operate on alternating voltage and current. Except for the shaded-pole motor, all ac motors operate because of transformerlike action. Since this involves both self-induction and mutual induction, these motors are known as *induction motors* and are fully covered in the next chapter.

Appliance motors

CHAPTER

5

A thorough and complete understanding of induction motors, as well as other types of ac motors used in appliance manufacture, requires a knowledge of such factors as reactance, capacitance, reluctance, impedance, and inductance. Because of the complexity of these subjects in respect to the time and space required to adequately explain them, all except the subject of inductance have been omitted from this book. For a general and practical understanding of how the motors currently used on home appliances start and operate, we believe only the basic knowledge of inductance which was given in the preceding chapter is required.

GENERAL INFORMATION

Motors versus Generators

Induction motors, as well as all other types, are similar in principle and operation to generators. Generators produce voltage and current, while motors utilize voltage and current to produce work. Likewise, generators and alternators produce motor action within themselves, while motors generate voltage and current by self-induction just as we have seen them generated in the coils of a transformer. The counter-emf generated in a motor protects the motor windings in the same manner as it protects the transformer coils; it limits the flow of current and keeps the windings at a safe temperature under normal operating conditions.

Horsepower Rating

Generators are rated according to their output in kilovoltamperes (kVA); motors are rated by horsepower or fractions thereof. This is based on the amount of work they are capable of doing measured in foot-pounds per second. Motors which are used to propel small fans have ratings such as $\frac{1}{25}$, $\frac{1}{75}$, and $\frac{1}{100}$ hp. Larger fractional-horsepower motors, used to drive compressors and other motor-driven appliances, have ratings such as $\frac{1}{6}$, $\frac{1}{5}$, $\frac{7}{32}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, and $\frac{3}{4}$ hp. Starting with 1-hp motors, the spread between ratings on integral-horsepower motors increases as the horsepower increases. For example, the usual ratings are $1\frac{1}{2}$, 2, 3, 5, $7\frac{1}{2}$, 10, 15, 40, 50, 75, and 100 hp.

The horsepower of a motor has, in most instances, a direct bearing upon its type, as does the application for which the motor is to be used. Each type has certain advantages over the others in respect to its application. In other words, one type may be suitable for certain applications but, because of its limitations and the economics involved, would not be suitable for others.

There are two general classifications of motors: external motors, such as those used on most washers and dryers, and internal motors, such as those hermetically sealed within most refrigerator compressor housings. Both classifications, however, have the same major components.

Major Components

Because of the similarity between generators and motors, it stands to reason that they also have the same major components: a stator containing coils of wire around pole pieces, and a rotating member.

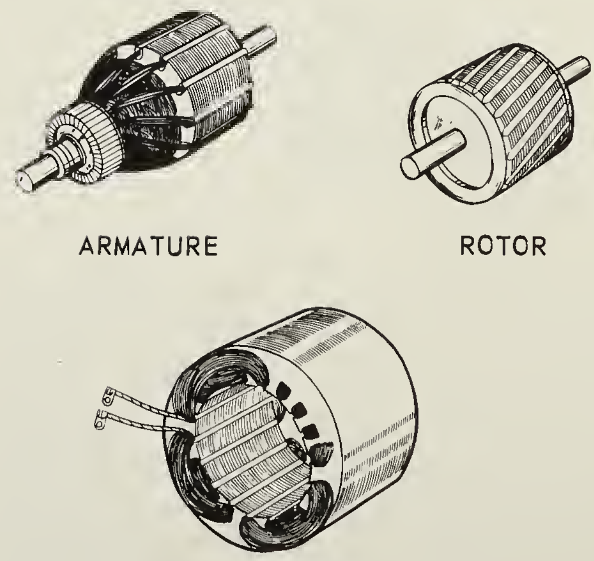


Figure 5-1. The principal motor parts.

Figure 5-1 illustrates the basic major components of induction motors. When the rotating member has a commutator and wound loops of wire, it is called an *armature.* When no commutator is required and metal bars and rings are used, the rotating member is called a *rotor.*

A brief discussion of ac motors using armatures will be given a little later. To understand the construction and operation of the first ac motors built, as well as that of modern motors, let us discuss the rotor illustrated in Fig. 5-2. It consists of a cylindrical core made of many laminations of readily magnetized metal. Copper or aluminum bars are embedded in the core as illustrated and both ends of the bars are bonded to a copper or aluminum ring. This arrangement

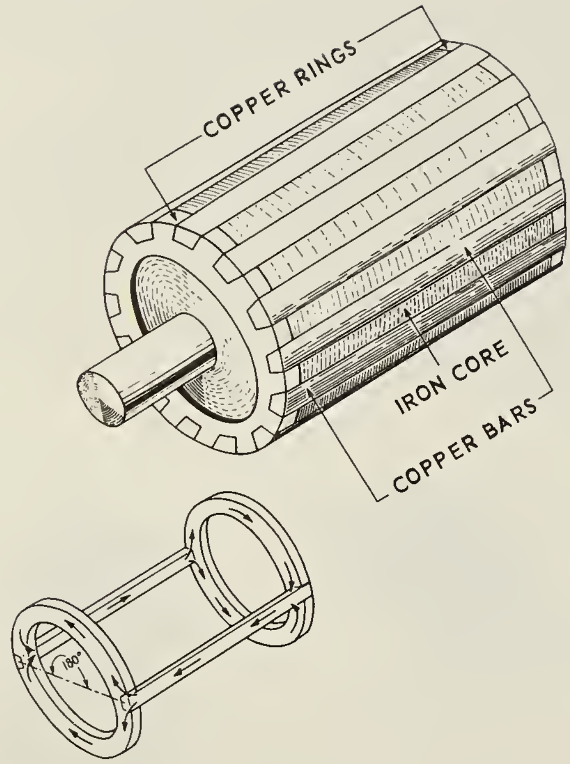


Figure 5-2. The motor rotor.

Two voltages are available from the service shown in Fig. 5-3; 240 V from all three lines, and 120 V when a circuit is between L_1 or L_2. Older house service had two lines, L_1 and neutral, supplying 120 V only.

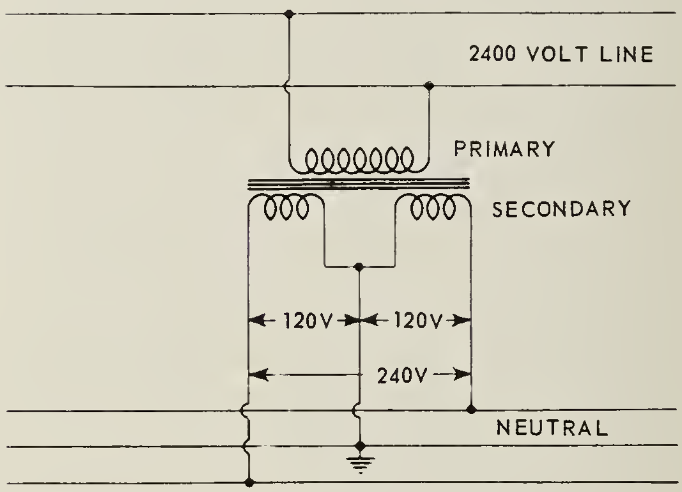


Figure 5-3. A three-wire ac circuit supply.

produces the appearance of a revolving squirrel cage, and for this reason we call it *squirrel-cage rotor*. The metal rings serve to complete a series of many closed loops of conductors for current flow. For example, each bar has another one directly opposite it. When two opposite bars are in the proper time or phase relationship with a stator pole piece, the rings complete a path for the current to flow through the two bars as it would in any closed loop. One pair of bars and the rings are also shown in the illustration.

In Chap. 3, we mention "phase" as part of ac circuits. At that time, it was mentioned that a single-phase circuit is one that supplies voltage from one set of alternator (or generator) coils. The alternator could be either a single- or three-phase type. A single-phase component, when broken into its simplest form, is always served by two lines. Modern single-phase house service is generally three lines—one from each side of a transformer secondary coil, and the third a ground or neutral line from a center tap on the secondary.

In a three-phase circuit the voltage is supplied from a three-phase alternator, which has three sets of coils. The coils are spaced 120° apart, and even though the voltage generated in each coil is equal, there is a timing difference ($\frac{1}{180}$ s in 60-Hz, three-phase) between the voltage peaks of each phase. When only three-phase components are served, the system requires only three lines; however, four and sometimes six lines are used.

Be sure to check the phase voltage before connecting a single-phase load. Voltages vary in the different supply systems. When three lines are used, the return is through the other two in each phase. When four lines are used, the fourth is a ground or neutral return. When six lines are used to a three-phase component, each phase is used as a single phase and has its own single-phase components built into the unit. By properly connecting into a three-phase supply, single-phase loads (motors, lights, etc.) can be connected across any one of the three phases. When using single-phase loads on a three-phase system, always try to balance the loads on the three phases as closely as possible.

This presents a balanced load across the three sets of coils in the alternator.

Motor Phases

As was stated in Chap. 3, motors are available in single-phase and three-phase. For the latter, a special three-phase service entrance is necessary. Three-phase current is furnished by the power company and is usually required when the motor load is in excess of 5 hp. A three-phase motor does not require any special electric components. It has strong starting torque, high operating efficiency, and a lower initial cost than a single-phase motor of comparable size. The three-phase motor has three individual windings, each with its own phase voltage impressed across it. Therefore, the currents will start at different times in each winding when the voltages are first impressed across them. The timing sequence causes a very strong starting torque. Each winding might be visualized as the thumb and first two fingers of your hand spread evenly around the rotor, providing a powerful magnetic hold to grasp the rotor and start turning it.

Since virtually all home appliances use single-phase motors, these are the motors we are primarily concerned with in this book.

TYPES OF MOTORS

Various types of motors are used in the many different kinds of electrical appliances. In this section we will discuss several types of electric motors and their uses.

Pure Single-Phase Induction Motors

The first ac motors ever built may be called *pure single-phase induction motors.* Although they operated fairly satisfactorily, they had one great disadvantage in that they were not self-starting. This meant that they had to either be started by hand or some mechanical means had to be provided to get them into operation. Fortunately, as the industry grew, methods for self-starting the motors were discovered.

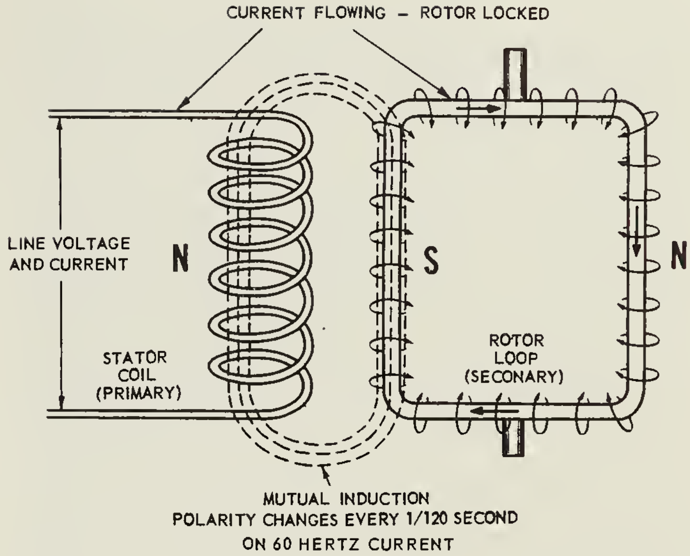


Figure 5-4. The transformer action of a single-phase motor.

Pure single-phase induction motors are less complex than the self-starting type. The forces that keep the rotor or armature revolving, however, are the same. Except for the method of starting, the following discussion applies also to all the self-starting induction motors.

It can be said that any induction motor is like a transformer having a movable or rotating secondary coil because it operates on the same basic principles of self-induction and mutual induction. In other words, the stator windings act as the primary coil of a transformer, while the loops of the rotor act as the secondary coil.

Figure 5-4 illustrates the similarity between a transformer and a single-phase induction motor. The coil of wire represents the single set of windings in the stator which is comparable to the primary coil of a transformer. The closed loop represents the loop which is formed by two diametrically opposite bars and the two rings of the rotor and which is comparable to a completed secondary circuit in a transformer. Due to the exceptionally large diameter of the bars and rings, the resistance of the loop is extremely low. This means that a very high current can be carried by the loop without self-damage. When a high current flows through the loop, strong magnetic fields of flux are produced around it.

The ability of the loops to carry an exceptionally high current at relatively low voltage, while producing strong magnetic fields, is one of the features of the rotor.

When the stator coil is energized, in effect, an electromagnet is produced. By mutual induction, the alternately expanding and collapsing magnetic field in the coil induces a flow of voltage and current in the rotor loop. This, in turn, produces an expanding and collapsing magnetic field around the loop which is the opposite polarity of that in the primary. Since unlike poles attract, the magnetic lines of flux lock the loop in place, and the rotor cannot turn. This is the reason why pure single-phase motors are not self-starting.

To help us understand how the rotor can be caused to turn and other basic facts pertaining to induction motors, two views are shown in Fig. 5-5. The stator windings illustrated are actually spaced in slots around the entire circumference of the stator. The spacing and arrangement of the windings determines the number of poles, which has a direct bearing on the speed of the motor. As the number of poles is increased, the speed is reduced. With the following exceptions, most appliance motors are the four-pole type. Many clothes washers equipped with automatic mechanisms are powered by six-pole motors. Some are equipped with four-speed mechanisms which incorporate a special motor designed to provide either four-pole or six-pole operation as determined by a switch setting. A small $\frac{1}{750}$ hp motor used in many automatic-defrost refrigerators is a two-pole type.

The second factor that determines the speed of the rotor is the speed of the alternator at the power plant. In the previous chapter we learned that a single-phase, 60-Hz alternator may be rotating at 3,600 r/min. The question is, what is the relationship between the speed of the alternator, the number of motor poles, and the speed of the motor rotor?

One of the unique features of induction motors is the revolving magnetic field produced in the stator. If the motor has two poles, the revolving field will be the same as the alternator speed: 3,600 r/min. If the motor has four poles, the speed is reduced to 1,800 r/min. In six-pole motors the speed is 1,200 r/min, while in eight-pole motors it is further reduced to 900 r/min.

In polyphase motors, a true rotating magnetic field is produced in the stator, which both starts the rotor in motion and maintains its operation. This is due to the placement of the stator windings and the sequence in which they are energized. In true single-phase motors, however, the single set of windings is incapable of producing a rotating field when electric energy is first applied. With this in mind, we will discuss what happens in the loops of the rotor. In Fig. 5-5A we see the loops of the rotor in cross section and their relative position to the stator poles. For the sake of explanation, we will use only one loop to show the opposing magnetic fields of the loops and stator pole as it would be for $\frac{1}{120}$ of a second, when the motor circuit is closed. Let us assume the pole on the left is an S pole. The pole opposite on the right in a four-pole motor is

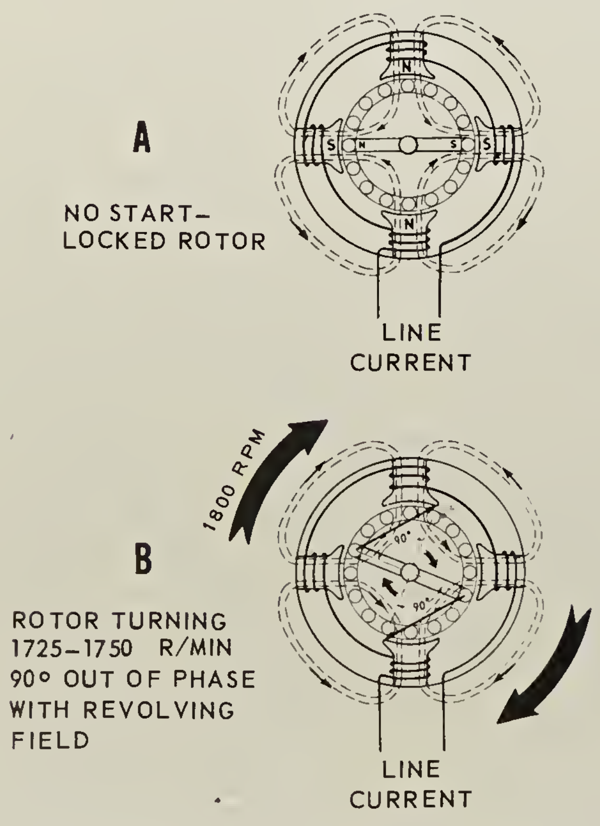


Figure 5-5. A pure single-phase induction motor.

also an S pole. The side of the loop adjacent to the left-hand pole then has an N polarity, while the other side has an S polarity. The forces of attraction on one side and those of repulsion on the other cancel each other, and the loop cannot turn. If, however, the rotor is given a sharp turn in either direction, the magnetism of the rotor will produce the effect of a rotating field in the stator windings. This causes the rotor to attain rated speed and to continue rotating as long as the windings are energized.

For a practical understanding of rotor operation, let us observe the single loop in Fig. 5-5B. If the motor is receiving its proper voltage and is operating under normal load conditions, at any $\frac{1}{120}$ of a second a loop of the rotor is 90° away from the forces of repulsion and attraction that keeps it revolving. This is called the *time relationship* or *phase-angle relationship*, and the rotor is said to be 90° out of phase with the main or running winding.

The rotor will always try to catch up to or rotate at the same speed as the revolving field but, fortunately, it never can. This is because of such factors as the weight of the rotor, the friction of the shaft bearings, and the windage, or air resistance. Also, if the motor is producing work, the load will tend to reduce its speed. The lagging behind of the rotor is called the *slip*. Because of slip, the speed of the rotor in a four-pole motor is reduced to approximately 1,725 or 1,750 r/min. The speed listed on the nameplate of external motors is the speed at which the rotor should revolve under normal operating eonditions. Six-pole induction motors have rotor speeds of 1,120 to 1,140 r/min.

Another factor affecting the inability of a motor to start is the weight of the rotor, which requires additional force to establish torque. *Torque* is a commonly used term which may be defined as a force that produces a twisting or rotating motion. Some motors have a high starting torque and require a low starting current, while others have a low starting torque and require more current to produce motion. The term "torque" also applies to the force that keeps the rotor turning. A high running torque is the force required to handle a heavy operating load.

One of the most desirable characteristics of induction motors is their ability to self-regulate their speed when operating within their rated capacity. To better understand this, let us assume that the motor is operating without a load. Since it is doing no work, the current demand is reduced, and the rotating fields of flux through which the rotor loops cut are relatively weak. The magnetic fields around the rotor loops are weakened proportionately, and the rotor retains its rated speed. As the load on the rotor shaft is increased, the motor calls for more current and the strength of the rotating field increases. As the load tends to reduce the rotor speed, the loops cut more and stronger lines of flux which, in turn, increases the opposing field around the loops. This keeps the rotor up to speed.

If the load on the rotor shaft exceeds the capacity of the motor, it will lag so far behind that the same relationship as between the rotor and stator illustrated in Fig. 5-5A will be established. This would mean the motor is stalled. The term *locked rotor* is used to describe this condition. Unless the load is relieved or adequate protection is provided, the heavy current demand will cause the stator windings to burn.

The next question is, how can induction motors be designed to be self-starting? There are three ways this can be accomplished, each of which will be explained in this chapter.

Repulsion-Induction Motors

Although this type of self-starting motor was not the first to be developed, it will be discussed first. The stator windings in repulsion-induction (RI) motors are arranged in the same manner as in any other induction motor having the same number of poles. The speed of the revolving stator field is therefore the same as in any other induction motor. The difference between the repulsion-induction motor and a single-phase induction motor lies in the rotating member and its associated parts.

Instead of having a squirrel-cage rotor, the repulsion-induction motor has an armature and

a set of brushes which engage the segments of the commutator. When a circuit to the motor is completed, the voltage and current take two parallel paths through it. One path is through the stator windings, thereby establishing the revolving magnetic field. The other path of current is through the brushes and a set of commutator segments which they engage. This completes a circuit through the armature loops that are attached to the segments, thus producing a magnetic field around the loops. In any $\frac{1}{120}$ of a second before the armature starts to rotate, the armature loops being energized are usually positioned 15 to 20° away from a point in the stator that is also receiving current. Because of the parallel flow of current, the magnetic fields around the loops and stator coils 15 to 20° away have the same polarity. Since like poles repel, the torque produced by repulsion is sufficient to provide self-starting. After the armature has started rotating, the self-starting feature is no longer required. Therefore, when the rotor has attained approximately three-quarters of its rated speed, the centrifugal force of the armature causes two important things to happen.

A brush-lifting device, with which most repulsion-induction motors are equipped, actuates to lift the brush bracket and brushes away from the commutator. At the same time, a device within the commutator, called a short-circuiting necklace, expands against the segments and, in effect, closes the ends of the loops. This converts the armature into a rotor, and it continues to rotate by the forces of attraction and repulsion, as in any single-phase induction motor.

When the circuit to the motor is opened, the armature slows sufficiently to allow both the short-circuiting necklace and the brushes to resume their original position in readiness for the next start.

Repulsion-induction motors have several advantages over other types of motors. They have a high starting torque and require a relatively low starting current. Because of this, they will start under lower line-voltage conditions and heavier starting loads than other types. They are, therefore, especially suited for farm use, where transmitted line voltages are normally low and the loads are often heavy. They are also suitable for large-tonnage refrigeration compressors and industrial equipment that require high starting torque.

The major disadvantages are the construction and maintenance costs. Although the brush-lifting device extends the life of the brushes and reduces the wear on the surface of the commutator, failure of these components is still a common cause of service complaints. The short-circuiting necklace is also a potential source of trouble.

For the past 35 years the manufacture of repulsion-induction motors for appliances has been reduced. This is due to several contributing factors such as the development and perfection of electrolytic capacitors. In refrigeration, introduction of modern refrigerants made possible smaller condensing units requiring less starting torque. Production of millions of hermetically sealed compressors for both domestic and commercial application was a major contributing factor, as were also the improvements made in split-phase motor design and construction and the economics involved in their production, which greatly reduced the demand for the repulsion-induction type of motor.

Pure Split-Phase Induction Motors

The split-phase induction motor was introduced in 1890 and was the first self-starting type designed for commercial use. Due to the complexities of the principle on which they start, the early motors were not entirely satisfactory. It required years of continued development to attain the high standards of present-day split-phase motors. Although much is known regarding the design and construction of these motors, authorities disagree on the exact principles by which they start. The following explanation of split-phase motor starting and operation is given only to provide a general and practical understanding of this subject.

Like the pure single-phase induction motors, these motors use a squirrel-cage rotor as the rotating member, thus eliminating the need for

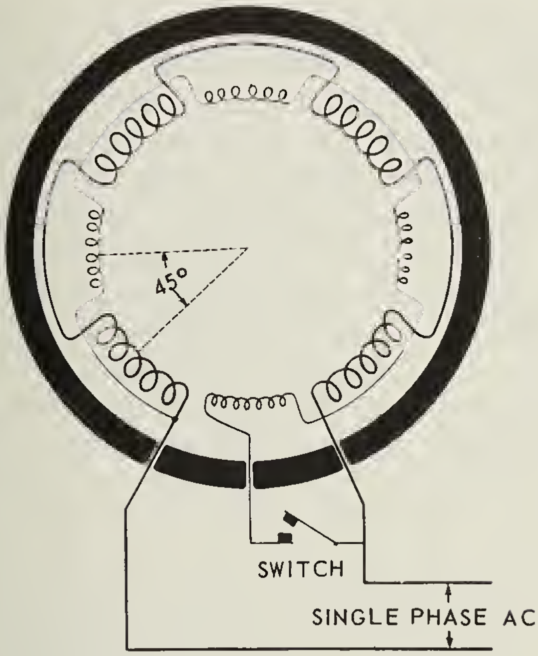


Figure 5-6. The stator of a split-phase motor.

brushes, commutators, and short-circuiting necklaces. Since these starting devices have been eliminated, it is apparent that some other means must be provided. This is accomplished by placing two sets of windings on the stator.

Figure 5-6 illustrates a schematic of the stator in a four-pole split-phase motor. The four sets of coils drawn in heavy lines represent the main or running windings, which are spaced and placed in the laminated stator frame. This is the same arrangement found in any four-pole induction motor.

The smaller coils drawn in lighter lines represent an additional set of windings called the phase or starting windings. They are formed of considerably smaller wire than the main windings. They are arranged in most of the same stator slots as the main windings but are placed directly between them. In other words, in a four-pole motor the phase windings overlap the adjacent main windings so that the center of each phase winding is mechanically 45° from the adjacent main windings. This spacing plays a significant role in the starting of all split-phase motors and in the running of a special type to be discussed later.

Because of the spacing of the phase windings, each phase coil produces its own pole piece for starting purposes.

From the illustration we observe that one terminal each of the phase and main windings are connected together and a common lead is provided externally for current to and from the source. Another lead, connected to the other end of the main winding, is for the same purpose. A circuit through the phase winding is opened and closed by one of three types of switches, each of which will be discussed later in this chapter. The switch is always connected in series with the phase winding.

Figure 5-7 illustrates a motor with the rotor installed and the switch to the phase winding closed. Because of the switch, current is being supplied to both sets of windings at the same time to follow a parallel path to the common terminal. This, in effect, produces two separate revolving magnetic fields which are sweeping progressively across the loops of the rotor. The two revolving fields, however, are not of the same strength, nor are they in step with each other. Since the phase windings are of smaller-size wire, they draw less current and produce weaker lines of force than the main poles.

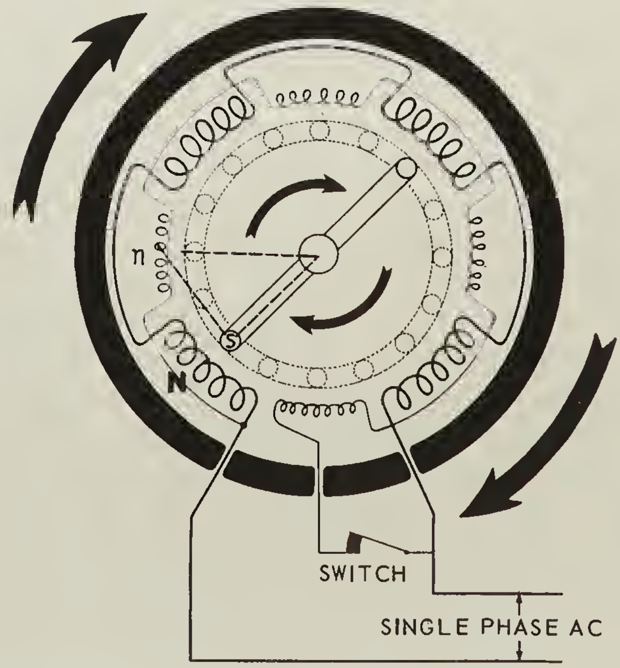


Figure 5-7. A split-phase motor.

Recalling discussion of the effect of counter-emf on current flow, the counter-emf developed in the phase windings has less effect on the flow of current than does the counter-emf developed in the main windings. The result is that the current in the main windings lags behind the voltage to a greater degree than the current in the phase winding. Since both the main and the phase windings are connected to a single supply voltage, the current flow in the main winding will lag behind the current flow in the phase winding. As a result, the magnetism produced in the two windings is out of phase or out of step. It is a matter of timing.

As explained earlier and illustrated in Fig. 5-4, the polarity of the rotor loop will be opposite to that of the adjacent stator coil. Since the main and phase windings reach their peak polarity strength at different times, the attraction of the rotor loop is first toward one, and then toward the other. This causes the loop to turn the rotor. Although the poles of the two windings are only 45° mechanically displaced, electrically this may produce the effect of a greater electric displacement or phase-angle relationship. After the rotor starts and the phase windings are removed electrically, the momentum of the rotor and the forces of attraction and repulsion keep the rotor turning as previously described.

Unless special switching or wiring arrangements are provided, split-phase motors always start and run in the same direction. In other words, the direction is established by the motor manufacturer and cannot be changed by switching external leads.

The time required for starting the rotor varies from a fraction of a second to several seconds, depending upon the load. Like repulsion-induction motors, once the rotor gets started, the self-starting feature is no longer required. The switching device used to supply current to the phase winding is designed to automatically open the circuit by, or shortly after, the time the rotor attains the rated speed. This is necessary in order to prevent the phase windings from overheating and burning within a short period of time. After the phase windings are removed electrically from the circuit, the rotor continues to rotate in the same manner as previously described. It is also affected by the same factors as those affecting any induction motor.

Generally speaking, pure split-phase motors are produced with horsepower ratings varying from $\frac{1}{20}$ hp to $\frac{1}{2}$ hp, inclusive. Usually, motors for lower horsepower requirements can be built in other types more economically, and motors having ratings higher than $\frac{1}{2}$ hp require additional assistance in starting and have a different name.

Compared to the repulsion-induction motor, pure split-phase motors [sometimes called *resistance start–induction run* (RSIR) motors] have a relatively lower starting torque and require a higher starting current. Under favorable voltage and load conditions, however, the advantages of the split-phase operation overbalance this apparent disadvantage. Because of the lower starting torque and higher starting current on split-phase motors, the starting voltage must be maintained at closer limits to the design voltage of the motor. In other words, if the starting voltage at the motor exceeds a 10 percent variation above or below its design, the motor may not start even though the load is normal. For example, if the motor is designed for 120 V and voltage at the motor drops below 103 or 104 V when it attempts to start, a locked-rotor condition may result.

From a voltage standpoint, most failures to start are due to low voltage rather than high. This is sometimes due to overloaded transmission and distribution lines, which are the responsibility of the power company. In many instances, however, the voltage drop is due to either undersized wiring or overloaded circuits within the customer's premises.

In addition to their other desirable features, the extensive use of split-phase motors can be attributed to their flexibility of application. They are used for small refrigerators, freezers, water coolers, dehumidifiers, etc., and as drive motors on automatic washers and dryers.

Split-phase motors require one of three types of starting switches: centrifugal, electromagnetic, or thermal.

Centrifugal switch. There are three major components of the centrifugal-switch assembly: the contacts, the moving contact arm, and the governor (Fig. 5-8). The contacts are in series with one side of the supply line and with the phase winding. Perpendicular to the shaft and attached to it is the governor assembly, which consists of a spring-loaded governor weight on a small rod. The spring-loaded contact arm has a circular inclined plane extending around the motor shaft. Due to its appearance, the weighted arm is commonly referred to as the "skillet."

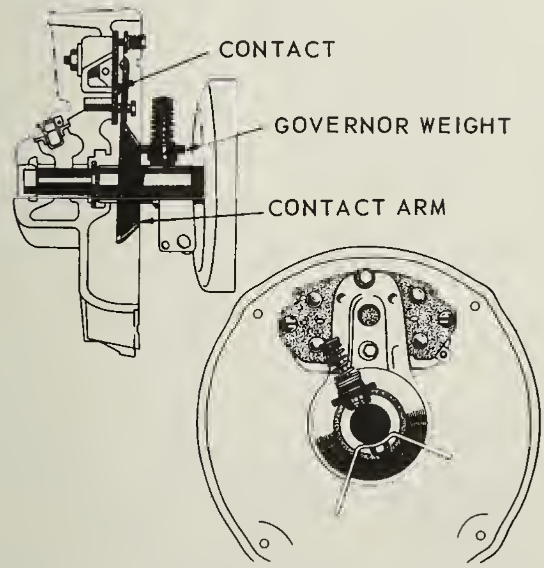


Figure 5-8. The parts of a typical centrifugal switch.

The relative position of the weight and skillet is illustrated in the idle position when the contacts are closed. When the shaft turns, centrifugal force causes the weight to move outward against the spring tension. This, in turn, permits the contact arm to move sufficiently to open the circuit to the phase, or start, winding. When the circuit to the running winding is opened, the rotor starts to reduce in speed and, as the governor weight moves toward the shaft, it contacts the inclined plane of the skillet and depresses the skillet so that by the time the shaft stops turning, the contacts have been reclosed in readiness for the next start.

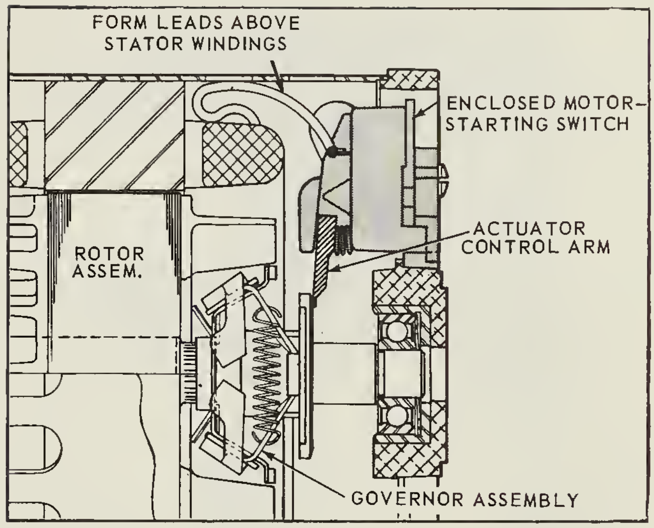


Figure 5-9. A centrifugal type switch in which the motor switch is incorporated.

Another type of centrifugal switch (Fig. 5-9) incorporates an enclosed motor-starting switch mounted in the motor end frame. The switch is operated by an actuator control arm. A governor assembly, mounted on the rotor shaft, contacts the control arm when the motor is at rest. This closes the starting-switch contacts to the phase windings. As the motor comes up to speed the governor moves away from the contact arm, allowing the switch contacts to open. This removes the phase winding from the circuit.

While the mechanically operated starting switches just described are suitable for external-type motors, such as those used for washers and dryers, they cannot be used where the motor is a part of a sealed assembly, such as a motor-compressor unit in a refrigerator. For these sealed motors an external starting relay is employed.

As previously noted, such external starting relays operate on two basic principles: thermal and electromagnetic. Electromagnetic relays are made in two different types: the current-sensitive type and the voltage-sensitive type.

Current-type relays. While there are many designs on the market, the basic components and the principles by which they operate are the same for all models of current-type relays (also called amperage-sensitive relays). In all instan-

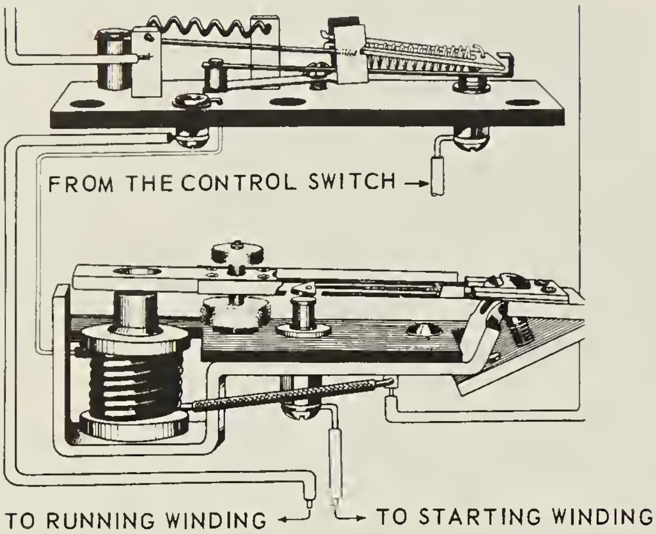


Figure 5-10. A current-type relay that is actuated by radiant heat.

ces, the relay is combined as an assembly with an automatic-reset motor-overload protector within a single case. A more complete coverage of protective devices will be made later in the book.

From the knowledge gained about electromagnetism in previous chapters, the construction and operation of the current-type relay can be readily understood. In the illustrations we can observe a solenoid coil wound around an iron core. The size of the wire and the number of turns have to be predetermined in accordance with the horsepower rating of the motor to which it is connected. The next important component of the relay is the moving contact arm, which is, in effect, an armature. It is made of a readily magnetized and demagnetized metal and is positioned adjacent to the electromagnet. To better understand how the relay is connected electrically in the motor circuit, a schematic diagram is shown in Fig. 5-12. Here we see that current is supplied to the relay through the overload protector and to the phase winding through the relay contacts.

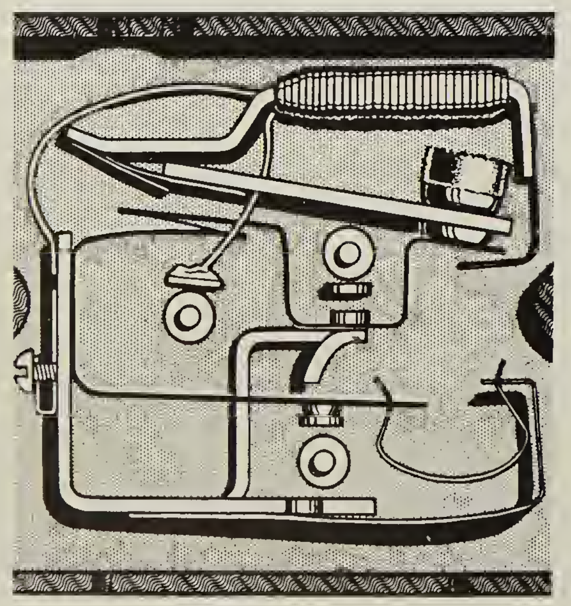


Figure 5-11. A current-type relay that is actuated by current heat.

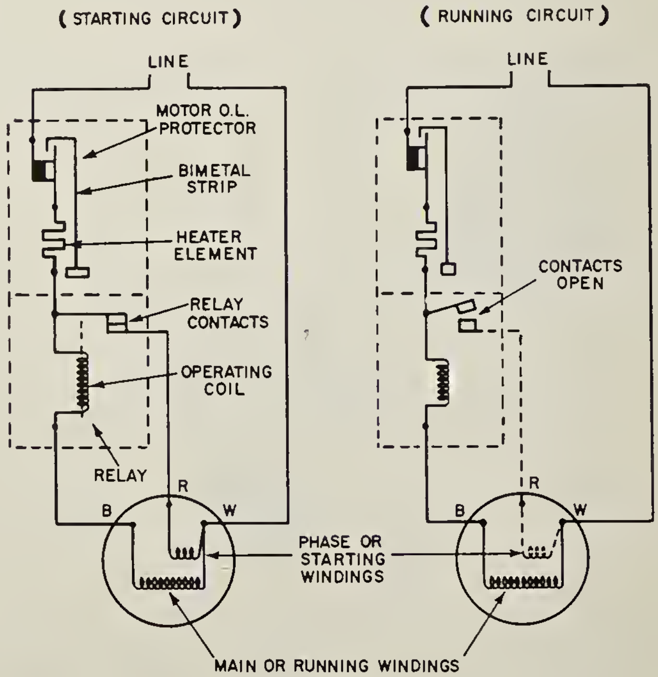


Figure 5-12. A schematic drawing of current relay in a compressor motor circuit.

The relay contacts in current-type relays are normally open when the thermostat contacts close. The question is, how are they caused to close? All of the current to the main motor winding passes through the overload protector and the solenoid coil. Since the motor cannot start by the main windings alone, the locked-rotor condition causes a high current to flow through the entire circuit. This, in turn, pro-

duces a strong magnetic field in the relay coil, which attracts the armature toward the core, thus closing the contacts. Current can now take a parallel path to and through the phase winding. As soon as the rotor approaches its rated speed, the current demand in the main windings and relay coil quickly reduces to normal and the magnetic field in the core becomes too weak to hold the contacts closed. Under favorable conditions the contacts of a current-type relay are closed only for a few seconds each time the motor starts.

Voltage-type relays. The coil in a potential-sensitive or voltage-type relay is wound with much finer wire and more turns than the coil in an amperage-sensitive or current-type relay, and its contacts are normally closed. It is used generally with a capacitor start–capacitor run motor (see p. 95) to remove the starting capacitor from the motor circuit (Fig. 5-13).

Voltage relays are so named because they actuate by counter-emf rather than by starting-line current. They are similar to current-type relays in that they have a solenoid coil and a moving armature to open and close the starting contacts. The solenoid coil, however, has a voltage rating considerably higher than the line voltage. For example, some voltage relays have coils rated as high as 265 V for applications where the line voltage is only 240 V. The coil of a voltage relay is wired in parallel with the starting winding and receives motor voltage at the instant of start. It is designed so that normal motor voltage will not produce a magnetic field of sufficient strength to open its contacts. As the motor starts, the turning rotor field and the

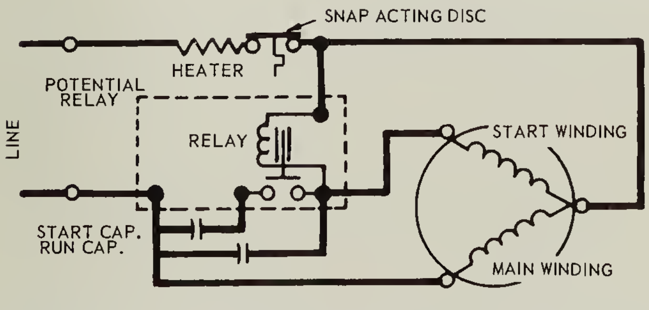


Figure 5-13. A voltage relay used in a motor starting circuit.

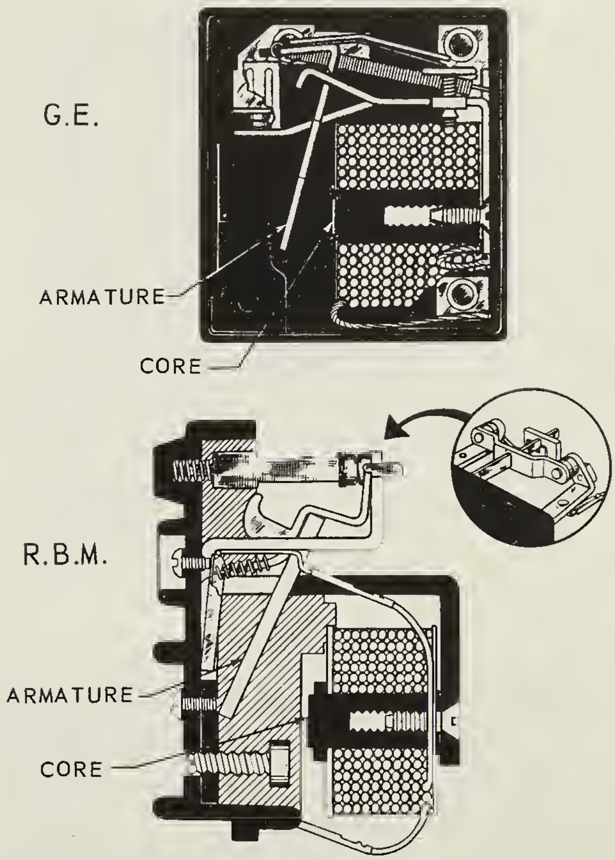


Figure 5-14. Internal view of two typical voltage type relays.

starting windings act as a generator, causing a voltage or back-emf (back-voltage) in these windings. As the motor increases speed, this voltage exceeds normal motor voltage. Since the relay coil is in parallel with the start windings, this same voltage is across its terminals. When the motor is at about 75 percent of its rated speed, this back-emf becomes sufficiently strong that the magnetic strength of the relay coil opens the circuit from the starting capacitor to the starting winding. The relay coil, however, is still in parallel with the starting winding and remains energized by the generator action or back-emf of the starting winding. This type of relay can also be position-sensitive, since it depends on magnetic strength and gravity to open and close its contacts.

Another important difference between current-type and voltage-type relays is the normal position of the starting contacts. Where the contacts are normally open on the current type, they are normally closed on the voltage type. Figure 5-14

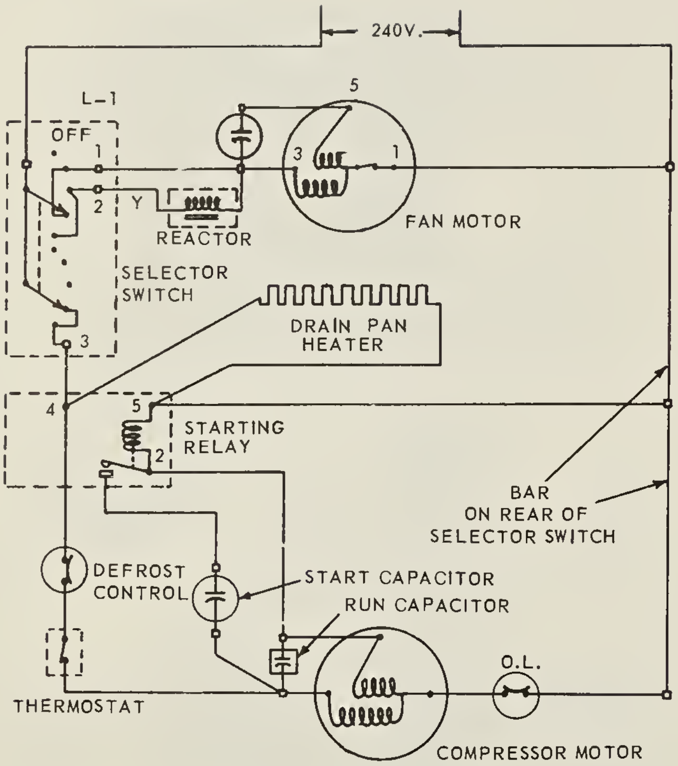


Figure 5-15. The electrical circuit diagram of a typical air conditioner (cooling cycle).

shows internal views of two typical voltage-type relays. The one shown at the top of the illustration is used on many room air conditioners designed for 120 V. The relay coil, however, is designed for opening the contacts at a point somewhere between 180 and 193 V and to reclose them when the voltage in the coil drops to 90 V or lower.

The other relay shown is used on many room air conditioners designed for 240 V. This relay is designed to open the contacts somewhere between 250 and 260 V and to reclose them at approximately 100 V or lower. Figure 5-15 illustrates a schematic wiring diagram of a circuit using the voltage-type relay. In operation, when the motor starts, an induced emf quickly develops and increases in the starting windings. This causes an increase in voltage and current through the relay coil. When the design voltage of the coil is reached, the current has produced a sufficiently strong electromagnet to attract the armature and open the contacts. During the running cycle, the voltage and current remain high enough to keep the armature attracted and the contacts open. When the motor circuit is opened and the voltage and current reduce to the drop-out point of the armature, the contacts reclose in readiness for the next start.

Thermal-type relays. The resistance- or heat-sensitive relay operates on the principle that metal will expand or grow when it is heated and contract or shrink as it cools (see p. 105). It is a variation of the current-type relay. The resistance or expansion rod is a part of the circuit to the main winding of the motor. As the motor starts, the starting current flowing through the fixed resistance of the expansion rod causes it to heat. As it heats it gets longer, causing the mechanical linkage attached to it to open the contact to the starting winding. This generally occurs in less than 1 s. This so-called hot-wire relay also serves as a current-overload switch. Should the motor load become excessive, causing it to draw too much current, the expansion rod will heat to the point that the current-overload contacts in series with the main winding will open, and the motor will stop.

Multispeed Motors

Many motors which provide alternate speed selections are built with additional contacts in the centrifugal switch and additional running windings to provide the desired speed. For example, two-speed motors like the washing-machine motor diagrammed in Fig. 5-16 are equipped with three terminals. These motors are

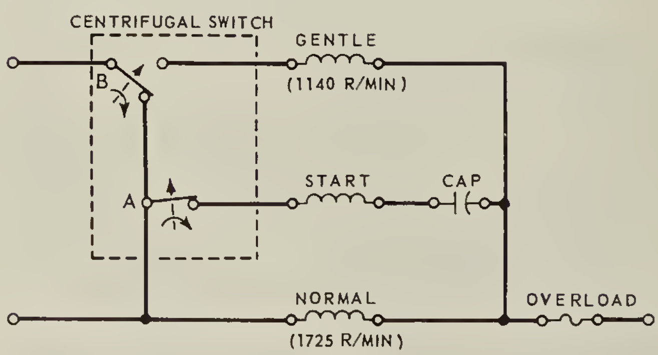


Figure 5-16. A two-speed motor.

designed with a starting winding, two sets of running windings, and a double-pole, single-throw centrifugal switch. More information on multispeed motors is given in *Major Appliance Servicing.*

Capacitor-Start Motors

The capacitor-start motor [sometimes called *capacitor start–induction run* (CSIR) motor] has the same basic construction as the type just described. It is so called only because it requires additional assistance from a capacitor to get the rotor started. The fact that capacitors can be used in conjunction with split-phase motors broadens their scope of application. Because of capacitors, construction costs are lower for both the manufacturers of motors and the producers of motor-driven products.

There are many applications that have a relatively high starting load, but a relatively low or normal operating load. If it were not for capacitors, more costly windings would have to be built into the motor just to provide a sufficient starting torque. On some applications, such as automatic clothes washers, the starting torque is so high that even a high-rated capacitor is not capable of producing the best starting conditions. For example, the starting ability of a $\frac{1}{2}$-hp motor may be required to get the mechanism started, while only a $\frac{1}{3}$-hp motor is required to keep it in operation. Because of this and similar conditions, more motors are being designed today for specific applications than ever before. For particular applications, more consideration is given to the starting and running torques of motors than is given to the horsepower rating of the motor. By proper selection of the stator windings, manufacturers of motors can produce a motor for any abnormal starting condition. This will ensure proper starting with the assistance of low-rated capacitors.

Capacitors that are designed for starting purposes *only* are called *electrolytic capacitors.*

Electrolytic capacitors. An electrolytic capacitor is an electrochemical device used mainly for improving the phase-angle relationship between the stator windings when the motor starts.

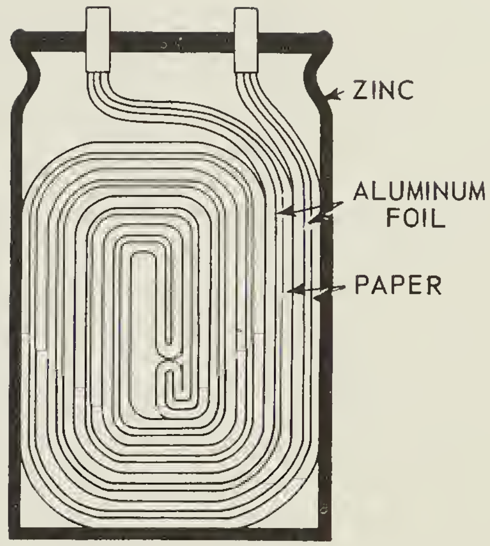


Figure 5-17. An electric capacitor.

A technical discussion of capacitors and their function in a motor circuit would become considerably involved. For this reason, only a general coverage of the subject will be given. Our discussion will pertain only to electrolytic capacitors as used on split-phase motors.

To better understand the construction of capacitors, let us observe a cutaway view of a typical one illustrated in Fig. 5-17. The material of which the container is made is of little significance. Although in the past zinc and aluminum have been widely used, many capacitors are now being made of plastic. Inside the container are two long strips of aluminum foil which serve as plates for storing free electrons. The foil has been processed to oxidize the surface, the oxide serving as the dielectric. Paper strips are used between the foil strips and are, in effect, conductors. The paper strips also keep the aluminum strips from touching each other when they are rolled together during assembly. After the strips are rolled they are dipped into a solution of glycol, borate, and water, which is the electrolyte. The water furnishes the hydrogen ions, which are needed for electrolytic action. The electrolyte performs the same function as the electrolyte used in batteries, which we have previously discussed. The rolled cartridge is then placed in the container and sealed. External terminals for the two metal strips are provided. In the same manner

that flashlight batteries are referred to as *dry batteries*, electrolytic capacitors are referred to as *dry capacitors*.

Before being placed in an electric circuit, a capacitor is normally discharged; that is, it has no voltage across its terminals. When it is placed in a circuit and 60-Hz alternating current is supplied to that circuit, electrons begin to flow onto one of the foil strips. As was stated on p. 10, this would cause other electrons to be repelled off of the other foil strip. As electrons pour onto the one foil strip and off of the other, a voltage is built up across the terminals of the capacitor. As this voltage becomes greater, the flow of electrons decreases. When the voltage has reached its maximum level (this is determined by the ac voltage supplied to the circuit or the counter-emf developed in the circuit) the electrons stop flowing into the capacitor. The capacitor is now charged. When the supplied 60-Hz alternating current reverses, the charge which built up on one foil strip bleeds off into the circuit while a similar charge builds up on the other foil strip. As a result the capacitor is again charged, but in an opposite direction. A capacitor installed in such a circuit charges and discharges 120 times a second.

Because current flows into a capacitor before a voltage is built up across its terminals, and because the current stops flowing at a time when the voltage reaches maximum, it is easy to see that the current and voltage are out of phase, or out of step with one another. In a capacitor circuit the current leads the voltage. (This is just the opposite of the relationship between current and voltage in a circuit with an induction coil.) Thus, we have another method for timing the flow of current in the main and phase windings of a motor in order to increase starting torque.

Capacitors have no polarity. When installing them in a circuit, therefore, no precautions are required as to which terminal should be used to connect a lead from the source of current.

All capacitors have a rated capacity in respect to the amount of free electrons thay can store. A unit of measure of capacity has been provided, which is the *farad* (F). A farad, however, is a very large quantity, and all capacitors used commercially are required to store quantities that are only millionths of a farad, or *microfarads*, abbreviated μF. The capacity of a capacitor depends upon two factors: the area of the aluminum foil and the thickness of the dielectric. The greater the area, and the thinner the dielectric, the higher will be the capacity.

The foil strips in many capacitors have been etched. By etching the foil, the capacity can be increased as much as 300 percent without increasing the amount of foil. For high starting loads, plain foil capacitors are often used. This is because of the excessive internal heat that occurs on etched surfaces under these conditions.

Because electrolytic capacitors are for starting purposes only and are normally in the circuit for only a matter of seconds, construction costs can be materially reduced as compared to another type to be discussed later. The manufacturers of electrolytic capacitors are allowed considerable tolerance in capacity ratings. In some instances, the rating, which is shown on the case, may be indicated as 135 to 160 μF. This means the actual capacity should be somewhere between these figures. More recently, some manufacturers are marking their starting capacitors with only one figure. The allowable tolerance in these instances is plus 20 percent, minus 0 percent, of the indicated figure.

A capacitor has also a voltage rating, which is marked on the container. This rating should not be mistaken as meaning the line voltage to which the equipment is connected. It is, rather, the maximum back-voltage (counter-emf) that the capacitor can tolerate for a short time without probable internal damage. In most instances, the voltage rating on electrolytic capacitors is only slightly higher than the line-voltage rating. If the starting-relay contacts, through which the capacitor receives its current, fail to open quickly, the counter-emf and high current produced in the combined sets of motor windings will soon cause the capacitor to overheat. This, in turn, will cause internal expansion that may tear the paper, the metal strips, or both. If the paper tears,

the capacitor becomes shorted and can no longer perform its function. If the metal strips tear, an open circuit will result and no current can flow to the phase windings. If the expansion is not sufficient to tear the strips, the high voltage may cause the metal strip to build up such high charges that the dielectric will puncture. This will cause a discharge through the paper and result also in a shorted capacitor. The heat also evaporates the water in the electrolyte and shortens the life of the capacitor. From this we can see that frequent or long starting periods can damage an electrolytic capacitor immediately, shorten its life, or reduce its capacity.

There is one other condition that overheating can cause which bears explaining. All capacitors have expansion plugs in their cases. In some instances the heat will either cause the plug to blow out or become sufficiently loose to allow some of the electrolyte to seep around the case and its mounting bracket. This can result in a grounded condition without apparently affecting the function of the capacitor. This ground can, however, cause an electric shock when the user touches the equipment if the equipment is not grounded.

It should be remembered that a capacitor-start motor should never be condemned as faulty without first checking the capacitor. Also, if the capacitor is found to be faulty, it should be replaced with one having the same microfarad and voltage ratings. It is also good to remember that capacitors can hold their charge after being removed from a circuit. To avoid receiving a jolt, you should discharge a capacitor before touching the two terminals.

There are several methods by which capacitors can be checked on the job. Five of these methods are (1) light bulb, (2) wattmeter and resistor, (3) voltmeter, (4) ohmmeter, and (5) ammeter. Open or shorted capacitors can be determined by any of these methods. The actual capacity, however, cannot be determined by either the light bulb method or the ohmmeter method. For this reason we recommend using either the wattmeter method or the voltmeter method. The ammeter method is somewhat hazardous, and care should be exercised in using it. Full details on the various ways to check capacitors are given in Chap. 8 in this book and in *Major Appliance Servicing*, and *Refrigeration, Air Conditioning, Range and Oven Servicing* in the series.

Let us continue our discussion of capacitor-start motors and their capacitors by observing the schematic wiring diagram in Fig. 5-18. As we see, the symbolic capacitor in the circuit is between the relay contacts and the phase winding of the motor. When a circuit to the motor is completed, the relay contacts will soon close for the same reason as previously described. If it were not for the capacitor, the rotor would remain locked because of the fact that the starting load is too great for the combined revolving stator fields to overcome. Because of the capacitor, the magnetic strength of the phase windings is increased and the phase-angle relationship between the windings and the rotor is improved. The timing of the peak strength of the magnetic poles is improved also. This gives the rotor a kick and it takes off. The armature of the relay then pulls away from the core, and the circuit through the capacitor and the phase windings is opened.

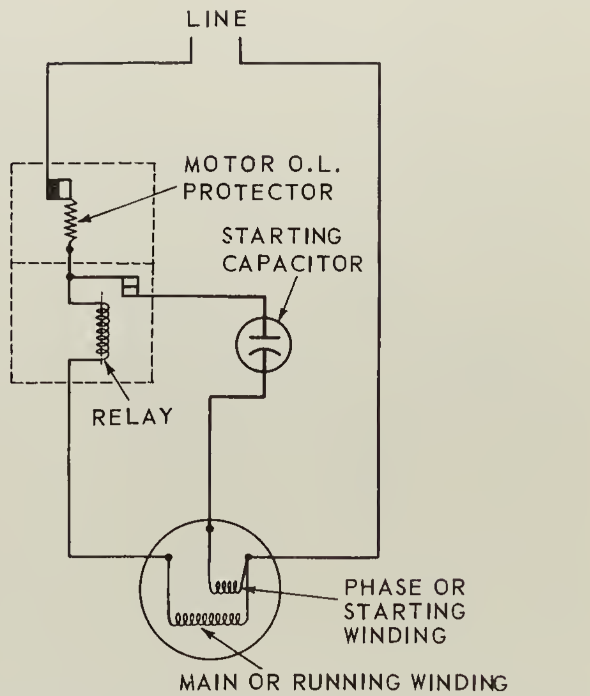


Figure 5-18. An application of electrolytic-type capacitor that is employed for starting only.

Tantalum capacitors. This is an electrolytic capacitor of more recent development than the aluminum electrolytic capacitor. It has approximately the same capacity range as the latter capacitor but is smaller in size. The anode is made of tantalum. The working temperature range extends to lower and higher extremes in the tantalum capacitor than in the aluminum capacitor.

Mylar capacitors. These electrolytic capacitors have exceptionally high insulation resistance, a low dielectric absorption, and a high power factor. They are also extremely stable, having a relatively small capacitance change with temperature variations over a range of 0 to 85°C. The mylar capacitor has an excellent resistance to humidity and moisture due to the casing material, which will not burn, soften, or melt at any operation temperature.

Permanent-Capacitor Motors

There are certain types of applications, such as the fan motor on room air conditioners, that have a relatively high operating load and a relatively low starting load. In these instances, one motor drives both the cooling fan and the condensing fan. As with any fan, the starting load is only that required to get the blades in motion, while the operating load increases as the amount of air being handled increases. Because of such applications, illustrated in Fig. 5-19, motors have been designed which are called *permanent-capacitor* or *pc motors.*

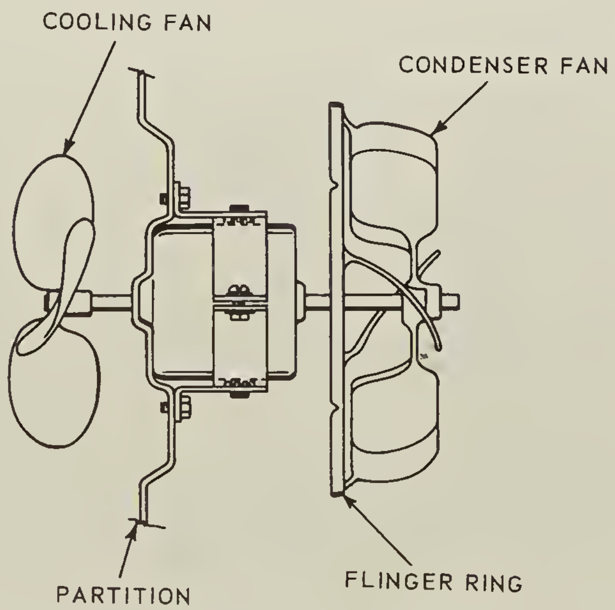


Figure 5-19. A common application of pc motor in an air-conditioner fan system.

This type of motor, like the capacitor-start type, is basically a pure split-phase induction motor. It differs only in the fact that the phase windings are energized during the entire operating period by a controlled amount of current. The motor is so named because a special type of capacitor is permanently in series with the phase winding. It might be said that the capacitor maintains the proper phase-angle relationship between magnetic fields that keep the rotor turning at full power but at a reduced current. In other words, if the capacitor were to be removed during operation, the running load might cause the rotor to slip so far behind that it would lock as previously described. In any event, the current demand of the motor would increase.

The question is, can motors be built for loads such as this that would not require permanent capacitors? Again, it is a matter of economics. Iron and copper cost more than capacitors. It should be remembered that increased production costs mean a considerable increase in the purchase price to the customer.

Motors that are subjected to relatively high operating loads require more magnetizing current and therefore have lower power factors. A permanent capacitor reduces the need for magnetizing current so that more of the current supplied by the power company is used for doing work. It can be rightfully said that permanent capacitors are power-factor-correcting devices. Installing banks of large capacitors is one means that power companies and industrial plants have for correcting power factor.

The next question is, what are permanent capacitors? Permanent capacitors are more commonly known as *oil- or liquid-filled running capacitors.*

Liquid-filled running capacitors. The basic principles by which running capacitors operate

are identical with those of electrolytic starting capacitors. They are also similar in basic construction except that the space around the rolled strips is filled with liquid before the container is sealed. For many years oil was used, but more suitable liquids have since been found. Liquid-filled capacitors differ considerably from the dry type in capacity range. With few exceptions, the smallest ratings are 2 μF and the highest are 50 μF. The manufacturers' tolerances are normally held to 10 percent higher or lower than the stated capacity. Capacitors with closer tolerances are produced for applications requiring more exact ratings. Compared with the dry type, liquid-filled capacitors are considerably more expensive. This is due primarily to the closer capacity tolerance which the manufacturer is required to maintain. The closer the tolerance, the higher will be the cost.

The voltage rating of liquid-filled capacitors is always considerably higher than the line voltage. Since the capacitor is always in the circuit and both sets of stator windings are energized, the counter-emf in the starting winding is always higher than either the counter-emf in the main winding or the line voltage. In other words, the starting windings are under the influence of both their own self-induction and the mutual induction of the stronger current in the main winding. This means that the capacitor must be built to withstand this high induced voltage. Voltage ratings of over 300 V are quite common.

Due to the more rugged construction, the low capacity ratings, and the liquid bath, internal heating is no problem. This type, therefore, is permanent.

Figure 5-20 shows a schematic wiring diagram of a circuit using permanent capacitors. Since the phase windings remain energized, no starting switch is required.

Some manufacturers have starting components available for the permanent split-capacitor type of motor. These kits are to be used if marginal voltage conditions are encountered or if the motor fails to start for some other reason. Starting components consist of a potential relay and a small starting capacitor. When these starting components are installed, the schematic of the motor looks exactly the same as the capacitor start–capacitor run motor, which is described next.

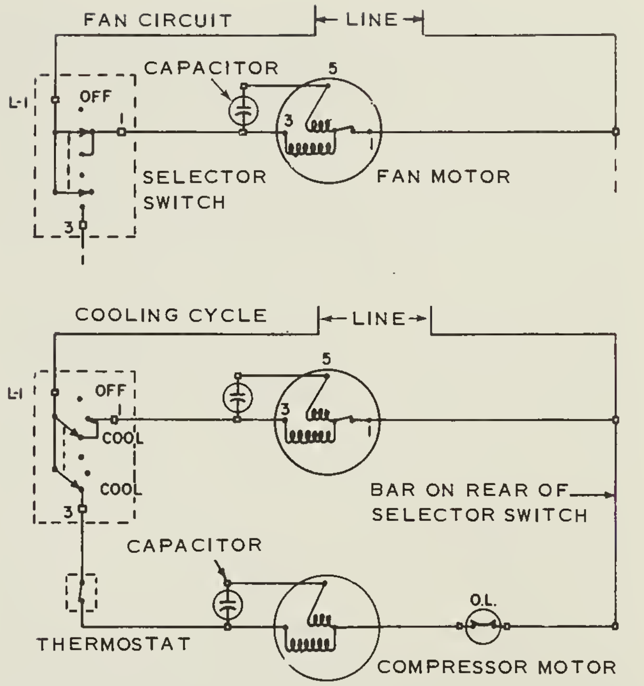


Figure 5-20. A typical air-conditioner electrical circuit using permanent capacitors.

Capacitor Start–Capacitor Run Motor

Two-valve capacitor or *capacitor start–capacitor run* (CSCR) motors are specially designed for applications that have both a relatively high starting *and* operating load. Some air conditioning units illustrate such applications. Although a running capacitor also assists in starting, the high starting load requires additional assistance. This is provided by an electrolytic capacitor that is automatically removed from the circuit after the rotor starts. The motor then operates as a pc motor. Since the compressor motor has a much higher starting and operating torque than the fan motor, higher-rated capacitors are required. For starting, the right combination of ratings between the two types of capacitors has to be predetermined by the manufacturer of the equipment.

When capacitors are connected in parallel, their capacities are additive. For example, if the starting capacitor has a rating of 180 μF and the running capacitor rating is 20 μF, the total capacitance for starting purposes is 200 μF. Because of the limited capacity range in which standard-size liquid-filled capacitors are produced, it is common practice to use two or more in parallel when higher than standard sizes are required. Combining liquid-filled capacitors of different ratings permits the selection of more exact ratings in respect to requirements. It should be remembered that properly selected running capacitors not only improve the power factor of the motor, but they also keep the best speed for maximum compressor capacity. When capacitors are connected in series, the total capacity is reduced. For example, two 100 μF capacitors in series produce a rating of only 50 μF.

Figure 5-21 shows a schematic wiring diagram of a typical application of a capacitor start–capacitor run motor. Here we observe that the running capacitors are connected in parallel and

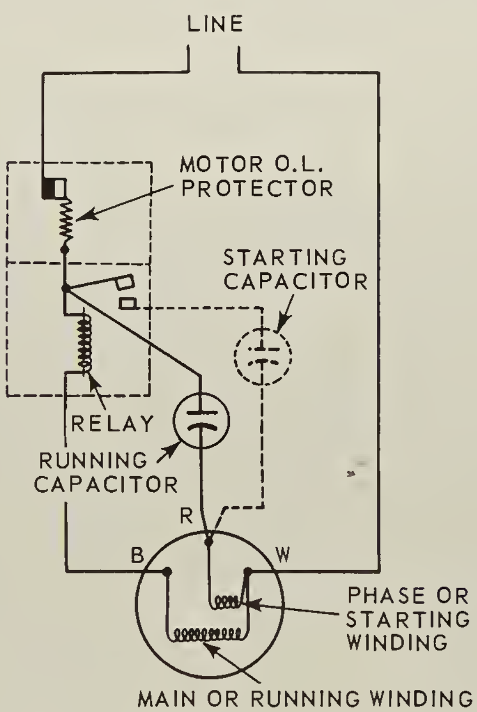


Figure 5-21. A schematic diagram showing the use of capacitors: electrolytic and liquid filled for starting; liquid filled for running.

that they are also in parallel with the starting capacitor. When the motor starts, all capacitors are in the phase-winding circuit. When the motor gets up to speed, the relay opens the circuit through the starting capacitor, but a continuous path for current is still provided through the running capacitors. The relays illustrated are current-type relays. Many room air conditioners today are using the voltage-type relay (see p. 89). Capacitor start–capacitor run motors are commonly used on applications through 5 hp.

Shaded-Pole Induction Motor

Up to this point in the chapter we have concerned ourselves only with motors that are used with the so-called major appliances—refrigerators, freezers, washers, dryers, room air conditioners, garbage disposers, dishwashers, etc. But we must remember that many small electrical appliances also employ motors—from the tiny motors in electric shavers up through the more powerful motors used on food mixers, portable power tools, sewing machines, and the like.

Shaded-pole induction motors (often called synchronous motors) are the simplest of all motors, but are suitable only for applications having a very low starting load and a relatively low operating load. In fact, they are tiny motors, usually ranging in horsepower from $\frac{1}{750}$ to $\frac{1}{30}$ hp, inclusive. Shaded-pole motors are self-starting but require no starting relay and no costly phase windings.

Figure 5-22 shows the stator and one loop of the rotor in a four-pole motor. The motor gets its name from the starting device. We observe that each pole has been notched to form a smaller pole around which is a ring of heavy copper called a *shading coil.* This produces a similar arrangement to that of a pure split-phase motor. In other words, the shading poles take the place of the phase windings, while the larger poles are for the same purpose as the main windings. There are, however, two significant differences. The distance between the adjacent large and small pole is considerably less than that between the comparable poles of a split-phase motor. Also, the shading pole is considerably smaller

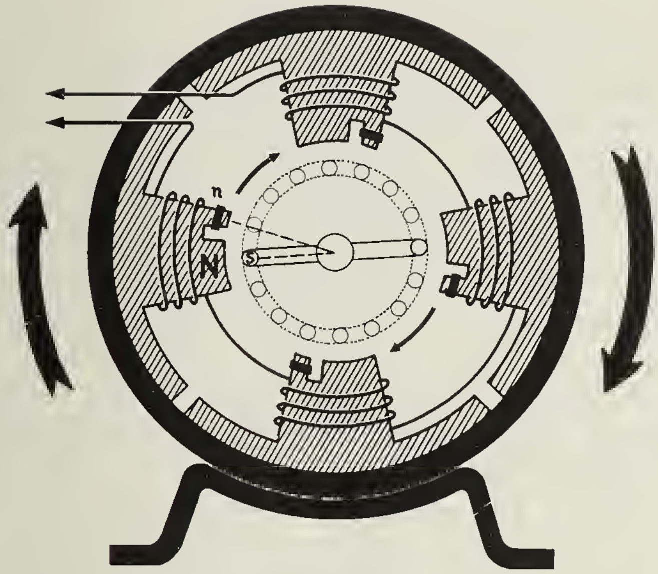


Figure 5-22. A shaded-pole motor.

and weaker than the phase windings. These two factors account for the relatively poor starting torque which is inherent with this type of motor.

When voltage and current are supplied to the main poles, the magnetic field expands and collapses progressively around the stator. As the field at N is expanding to its maximum, the opposing field in the adjacent motor loop is also expanding. By the time the rotor-loop field expands, the collapsing field in the main pole causes the shading pole to increase its magnetism to become a small N pole. The opposing fields of the rotor loop and shading coil, though relatively weak, cause the rotor to move always toward the shaded pole.

If it were possible to remove the shading coils after the rotor attains its rated speed, stronger running torque would be produced as on any single-phase rotor. Since this is not practical, the rotor is continually influenced by the polarity of the shading pole which, in effect, increases the slip of the rotor. In fact, even under normal operating load, the rotor is able to stay only a little ahead of its lock-in point. That is why these motors are relatively easy to stall. Fortunately, on $\frac{1}{80}$ hp or smaller motors the locked-rotor current is only slightly higher than the running current, neither of which is sufficient to burn up the motor even in a continuously stalled condition. Because of this, most shaded-pole motors require no overload protectors.

Another reason for the relatively low starting and running torques of shaded-pole motors is the wide air gap between the rotor and the stator. The combined fields of the main and shaded poles would make these motors objectionably noisy if a narrow air gap were used. The manufacturer, therefore, must compromise between the sound level and the performance of the motor. In spite of their apparent shortcomings, these motors produce economical and satisfactory results when used on applications for which they are intended. Since the shaded-pole motor requires no special starting components and is fairly simple in design, it is widely used. The main winding can easily be tapped for multispeed operation. It is frequently used for electric clocks, phonograph turntables, hair dryers, small fans, rotisseries, etc.

Series-Wound Universal Motors

The most commonly used motor in small home appliances is the *universal* or *series-wound* type. Such motors can be operated from either an ac or dc source. Figure 5-23 shows that the same current flows through the field and armature windings. Therefore, when the polarity is reversed, the magnetic fields of both the armature and the field coils reverse their polarities together. Thus, the reaction between the armature and the field winding is the same for both ac and dc motors.

The universal motor can be distinguished from

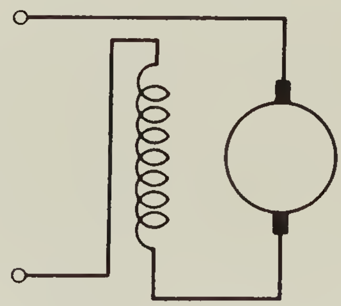


Figure 5-23. A series-wound universal motor.

the other types of motors mentioned in this chapter by its soft carbon brushes. (Service technicians frequently call them "brush-type" motors.) In fact, the rotating part is connected to the electric current through the brushes. In this type of motor, the rotating part is the armature. At one end of the armature there is a smaller-diameter section called the commutator, on which the brushes make contact. The universal motor may be arranged relatively easily for two or more speeds, and it is self-starting.

The universal motor is found in home appliances in ratings from $\frac{1}{50}$ to $\frac{3}{4}$ hp. It has a high starting torque but poor speed regulations. This latter term means that it slows down as the load is increased and will "run away" with no load. Actually the speed of this type of motor is determined by the load; the greater the load (the work it has to do) the slower the speed. Speed also varies with voltage. An example of this is the foot control on a sewing machine, which varies the voltage to vary the speed of the motor.

DC Motors

With the advent of small rechargeable batteries, some "cordless" small appliances such as electric knives, toothbrushes, personal care products, portable power tools, etc., employ the use of a dc motor. The two major differences between these motors and those previously discussed in this chapter are that (1) they operate on much lower voltages, and (2) the vast majority have permanent magnets instead of wound fields.

Figure 5-24 represents the simplest kind of dc motor. Actually, its operation is very similar to that of the dc generator described on p. 47. That is, a single horseshoe magnet or a pair of permanent magnets provides the stator's magnetic field, while the armature obtains its magnetic field from the electromagnetic effect created by the armature windings. These armature windings, which may be a single set of wires or several sets, receive the necessary direct current from the batteries by means of a pair of brushes and a split-ring commutator. The com-

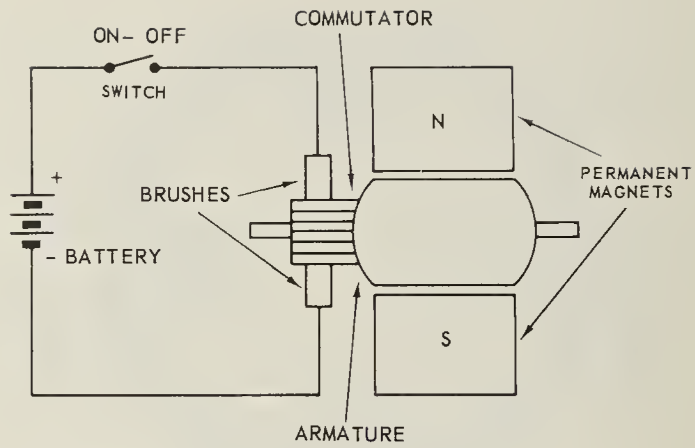


Figure 5-24. A typical dc motor.

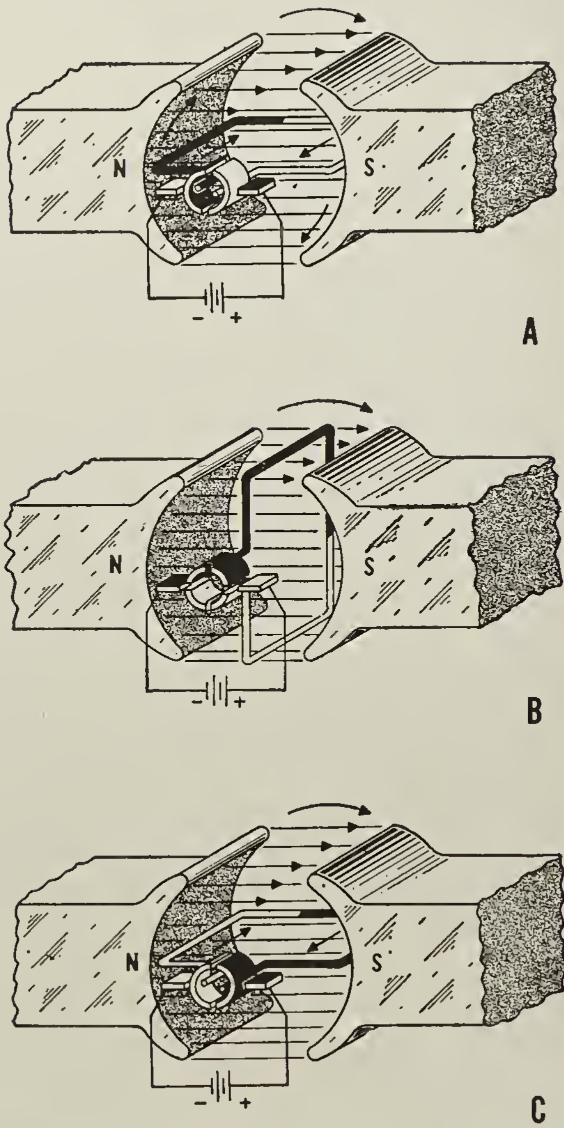


Figure 5-25. Continual rotation of an armature in a dc motor is made possible by commutator action.

mutator segments, which are usually made of copper, are fastened to the armature shaft. Like other armature-type motors, mica or hard-fiber material is used to insulate the commutator segments from each other and from the metallic armature shaft. The brushes, which are usually made of carbon, are fixed relative to the motor frame and slide across the commutator segments as the armature rotates.

In Fig. 5-25A, the armature is in a position in which the current flows through the brushes and commutator to the armature winding. This causes a magnetic field to be formed in a position approximately 45° clockwise from the like poles around the stator. As we know, like magnetic poles repel and unlike poles attract; thus, as the armature rotates in a clockwise direction, its North pole will attempt to align itself with the stator's South pole. As the armature's poles nearly reach this alignment with those of the stator (Fig. 5-25B), the commutator segments are so positioned that the armature current reverses direction. When this occurs, the polarity of the magnetic field also changes, and this causes the armature to turn further in a clockwise direction. Since the current through the armature reverses direction each time the unlike magnetic poles almost reach alignment, the armature will continue to spin and produce power to drive the appliance until the dc supply is turned off.

Because most permanent-magnet dc motors operate at high speeds—anywhere from 2,000 to 20,000 r/min—most are used in conjunction with reduction gears that reduce the rate of spin to a more useful level. In addition, this reduction of the speed also tends to increase the effective torque by a proportional amount.

The servicing techniques of permanent-magnet dc motors, series-wound universal motors, and the shaded-pole induction motors are detailed in Chap. 2 of *Small Appliance Servicing Guide.* The repairing and servicing of major appliance motors are explained in *Major Appliance Servicing* and *Refrigeration, Air Conditioning, Range and Oven Servicing.*

Appliance protective and control devices

CHAPTER

6

Electricity, when properly controlled, is of vital importance to the operation of appliances. When it is not properly controlled, however, it can become dangerous and destructive. It can destroy components or complete appliance units; it can injure personnel and even cause their death. (See Chap. 9 for safety rules to follow when working with electricity.)

It is of the greatest importance, then, that all precautions necessary be taken to protect the appliance circuits and units and to keep the electricity under proper control at all times. In this chapter some of the devices that have been developed to protect and control appliance circuits are discussed.

When an appliance unit is built, the greatest care is taken to ensure that each separate electric circuit is fully insulated from all others so that the current in a circuit will follow its intended individual path. Once the unit is placed into service, however, there are many things that can happen to alter the original circuitry. Some of these changes can cause serious trouble if they are not detected and corrected in time.

Perhaps the most serious trouble we can find in a circuit is a direct short. Recall from Chap. 1 that this term is used to describe a situation in which some point in the circuit where full system voltage is present comes in direct contact with the ground or return side of the circuit. This establishes a path for current flow that contains no resistance other than that present in the wires carrying the current, and these wires have very little resistance.

According to Ohm's law, if the resistance in a circuit is extremely small, the current will be extremely great. When a direct short occurs, then, there will be an extremely heavy current flowing through the wires. Suppose, for instance, that the two leads from a battery to a motor came in contact with each other. Not only would the motor stop running, because of the current going through the short, but the battery would become discharged quickly (perhaps ruined), and there would also be a danger of fire.

The battery cables in our example would be very large wires, capable of carrying very heavy currents. Most wires used in electric circuits are considerably smaller, and their current-carrying capacity is quite limited. The size of the wires used in any given circuit is determined by the amount of current the wires are expected to carry under normal operating conditions. Any current flow greatly in excess of normal, such as there would be in the case of a direct short, would cause a rapid generation of heat.

If the excessive current flow caused by the short is left unchecked, the heat in the wire will continue to increase until something gives way. Perhaps a portion of the wire will melt and open the circuit so that nothing is damaged other than the wires involved. The probability exists, however, that much greater damage would result. The heat in the wires could char and burn their insulation and that of other wires bundled with them, which could cause more shorts. If a fuel or oil leak is near any of the hot wires, a disastrous fire might be started.

To protect electric systems from damage and failure caused by excessive current, several kinds of protective devices are installed in the systems. Fuses, circuit breakers, and thermal protectors are used for this purpose.

OVERCURRENT PROTECTORS

For many years fuses have been more widely used than any of the other types of overcurrent protector. They are still used for many applications. More recently, however, thermal and thermal-magnetic types of circuit breakers have gained widespread acceptance for use in main switch boxes of homes and business establishments, among other applications.

Fuses

In spite of the fact that fuses have a rather limited use in appliances today, many of the electric circuits to which appliances are connected are fused, and these remote fuses can have a direct bearing on an appliance's operation.

Regardless of their type, fuses are selected on the basis of the type of load for which they are used—for pure resistance loads or for inductive loads. For the protection of all conductors except those used for motor circuits,

the fuse must not be larger than the maximum ampere rating of the conductor. If the conductor rating, however, does not correspond to a standard-size fuse, the next larger fuse may be used. Standard sizes range from 15 to 40 A in 5-A increments and from 40 to 80 A in 10-A increments. The next ratings are 100, 125, 150, 200, and 250 A. From 300 to 600 A inclusive, there is a spread of 100 A.

Before discussing the fuses used for motor protection, let us observe a cutaway view of the various types of fuses illustrated in Fig. 6-1. Ordinary link fuses of both the plug and cartridge type are suitable primarily for protecting building wiring and pure resistance loads with amperage ratings of 15 A or higher. Like any type of fuse, the ordinary link type will protect against a short circuit and, if properly selected, will protect the wiring when its maximum current capacity has been gradually reached. They are not, however, suitable for motor protection. If the ordinary type of fuse were selected to protect the motor during its operation, it would most likely blow when the motor started.

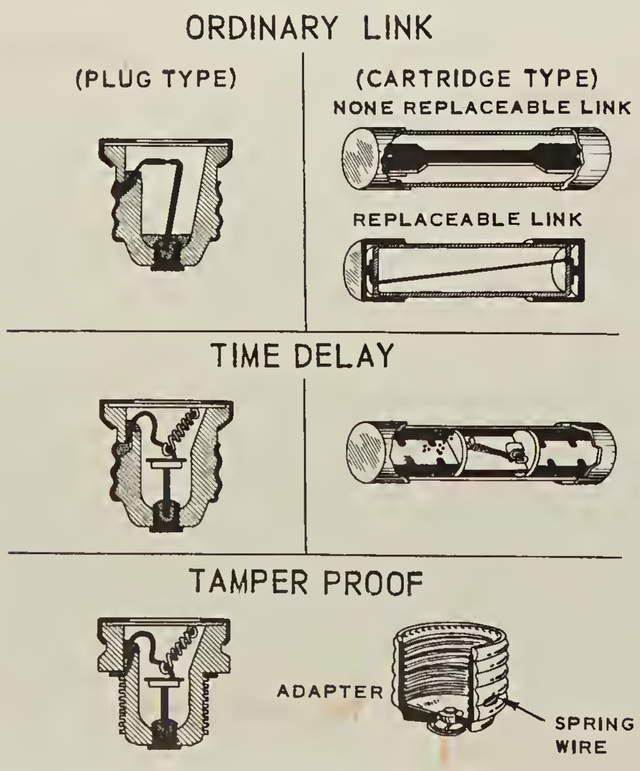


Figure 6-1. Standard types of fuses.

This would be especially true on high starting loads or longer-than-usual starting periods. For this reason, time-delay fuses were developed. Those illustrated are Fusetrons, the best-known and most widely used brand. Time-delay fuses of this type have two elements. One is a link, similar to that in ordinary fuses, which protects the circuit against shorts. In the plug type, the other element is a small container or pot called a *thermal element* attached to the center terminal. The pot is filled with a solderlike material which has a low melting point.

The link for short circuits is attached to the thermal-element lid and to the metal screw base which is sized for standard Edison-type screw sockets or receptacles. A small spring exerts a pulling tension against the lid. This means the link and thermal element are electrically in series. When installed, the Fusetron completes a circuit as any other type of fuse.

If for any reason the operating current causes the solderlike material to reach 280°F, this material melts sufficiently for the spring to pull the lid off the thermal element and break the circuit. This compares to the 786°F required to melt the link of ordinary fuses. The low resistance of the thermal element provides a time lag, permitting a motor to have a 500 percent overload for nearly 11 s without damaging the motor or blowing the time-delay fuse. Compare this with $\frac{1}{4}$ s for ordinary fuses. Because of their long time lag, time-delay fuses prevent useless shutdowns due to starting loads and other harmless overloads.

To conform with codes, plug fuses, regardless of their type, are not available in ratings over 30 A; any rating over 30 A must be in the cartridge type. Time-delay cartridge fuses are available in a wide variety of ratings less than 15 A.

The tamperproof time-delay fuses are available only in the plug type. The one shown in the illustration is called a Fustat and is especially suited for application where close and exacting ratings are required and where an improperly selected replacement fuse could result in serious damage to the equipment. Its tamperproof

feature is made possible by a special adapter which has standard Edison-base external threads and whose internal threads coincide with the base of Fustats having ampere ratings within a very limited range. Once the adapter is screwed into the standard receptacle, it cannot be unscrewed. This is due to the fact that the end of a steel wire extending through the side of the adapter digs into the threaded portion of the receptacle when an attempt is made to unscrew it.

To assist the service technician in selecting the proper rating when replacing a blown Fustat, the threaded porcelain body and a printed disk in the corresponding adapter are the same color. They are colored as follows:

$\frac{3}{10}$ to $1\frac{6}{10}$ A . . . . .Lavender
$1\frac{8}{10}$ to $3\frac{2}{10}$ A . . . . .Gray
$3\frac{1}{2}$ to $6\frac{1}{4}$ A . . . . .Brown
7 to 14 A . . . . .Pale blue
15 A . . . . .Dark blue
20 A . . . . .Orange
25 A . . . . .Green
30 A . . . . .Green

From this we can note that there are eight different types of threads used on the Fustats and their corresponding adapters.

Table 6-1 lists the fuse size for branch-circuit (see p. 134) and motor protection. Any branch circuit which supplies current to both pure resistance and inductive loads should be protected with time-delay fuses. These ratings are for single-phase current only.

Inspect blown fuses. Many times the condition of a blown fuse can tell you something about what has happened. If it is pitted at the bottom, the fuse was loose (a common problem) or it has been subjected to excessive vibration (panel is incorrectly mounted). If the threads are discolored, there is a loose connection inside the panel in the affected circuit. If the window of the fuse is discolored, the blow was caused by a short circuit, which must be found and corrected. If the element is broken, rather than melted away, the circuit was temporarily overloaded. More on troubleshooting fused circuits is given in Chap. 7.

Table 6-1. Branch-circuit and motor protection (fuse type)

Motor		Branch circuit*		Motor protection†	
hp	Amperage rating	Ordinary fuse	Fusetron	Normal service	Heavy service
		120 V			
$\frac{1}{6}$	4.4	15	7	$4\frac{1}{2}$	5
$\frac{1}{4}$	5.8	20	10	$5\frac{6}{10}$	$6\frac{1}{4}$
$\frac{1}{3}$	7.2	25	12	7	8
$\frac{1}{2}$	9.8	30	$17\frac{1}{2}$	10	12
$\frac{3}{4}$	13.8	45	25	15	$17\frac{1}{2}$
1	16.0	50	30	$17\frac{1}{2}$	20
$1\frac{1}{2}$	20.0	60	35	20	25
2	24.0	80	40	25	30
		240 V			
$\frac{1}{6}$	2.2	15	$3\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{1}{2}$
$\frac{1}{4}$	2.9	15	5	$2\frac{8}{10}$	$3\frac{2}{10}$
$\frac{1}{3}$	3.6	15	6	$3\frac{1}{2}$	4
$\frac{1}{2}$	4.9	15	8	5	$5\frac{6}{10}$
$\frac{3}{4}$	6.9	25	12	7	8
1	8.0	25	15	8	9
$1\frac{1}{2}$	10.0	30	$7\frac{1}{2}$	10	12
2	12.0	40	20	12	15
3	17.0	60	25	$17\frac{1}{2}$	20
5	28.0	90	45	30	35

* Does not give motor protection.
† Also gives branch circuit protection.

Circuit Breakers

A circuit breaker is designed to break the circuit and stop the current flow when the current exceeds a predetermined value. It is commonly used in place of a fuse and may sometimes eliminate the need for a switch. A circuit breaker differs from a fuse in that it "trips" to break the circuit and may be reset, while a fuse melts and must be replaced.

Several types of circuit breakers are commonly used. One is a magnetic type. When excessive current flows in the circuit, it makes an electromagnet strong enough to move a small armature, which trips the breaker. Another type is the thermal-overload or breaker switch. This consists of a bimetallic strip which, when it becomes overheated from excessive current,

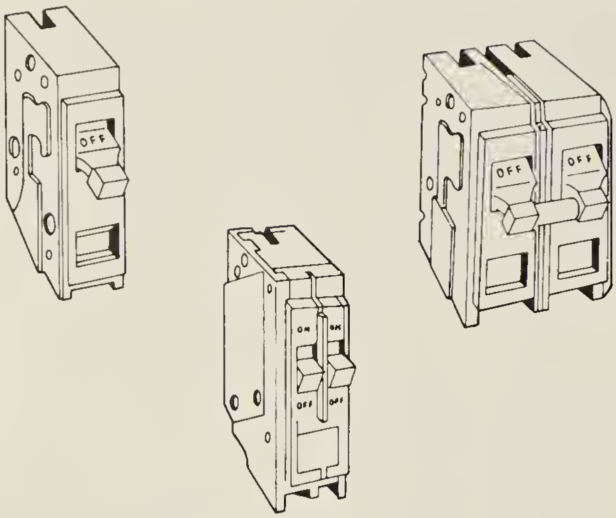


Figure 6-2. Typical circuit breaker.

bends away from a catch on the switch lever and permits the switch to trip open.

Some circuit breakers must be reset by hand, while others reset themselves automatically. When the circuit breaker is reset, if the overload condition still exists, the circuit breaker will trip again to prevent damage to the circuit.

One common type of circuit breaker now being used is depicted in Fig. 6-2. This breaker is designed for front or rear connections as required and may be mounted so as to be removable from the front without removing the circuit-breaker cover. The voltage ratings of this breaker are 500 V ac (60 Hz) or 250 V dc, with a maximum current capacity of 250 A. Trip units for this breaker are available with current ratings of 125, 150, 175, 225, and 250 A.

The trip unit houses the electric tripping mechanisms, the thermal element for tripping the circuit breaker on overload conditions, and the instantaneous trip for tripping on short-circuit conditions. The automatic-trip devices of this circuit breaker are "trip-free" of the operating handle; this means the circuit breaker cannot be held closed by the operating handle if an overload exists. When the circuit breaker has tripped due to an overload or a short circuit, the handle rests in a center position. To reclose after automatic tripping, the handle must be removed to the extreme OFF position which resets the latch in the trip unit; then the handle must be physically moved to the ON position. Metal locking devices are available that can be attached to the handles of circuit breakers to prevent accidental operation.

Magnetic circuit breakers. The basic construction of a typical magnetic circuit breaker is shown in Fig. 6-3. In Fig. 6-3A we observe the basic components and their relative position when a circuit through the device is completed. Under normal operation the current strength through the solenoid coil is not strong enough to attract the armature. If an overload is placed on the circuit, the increased magnetism in the coil attracts the armature and opens the circuit as illustrated in Fig. 6-3B. A manual reset button is provided externally which permits reclosing the contacts. Generally speaking, magnetic circuit breakers in appliances are not suitable for maximum protection of motors where accurate and close sizing of the protection is required.

Bimetal circuit breakers. As we know, substances expand when heat is applied and contract when heat is removed. No two substances

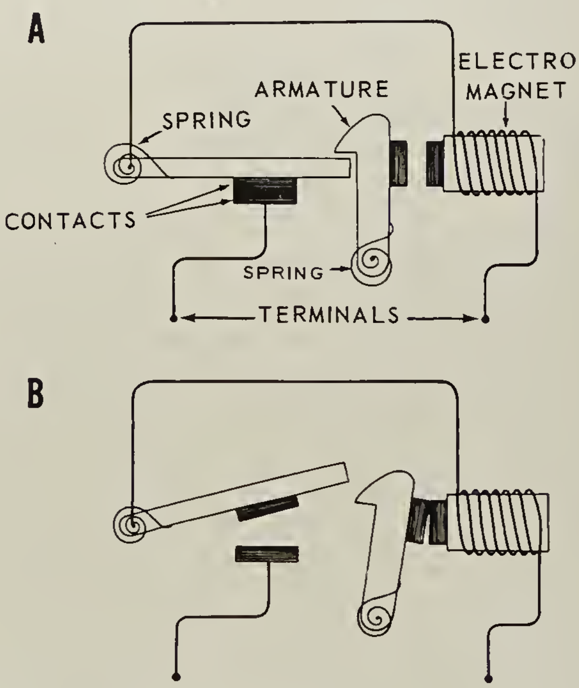


Figure 6-3. Operation of a magnetic circuit breaker.

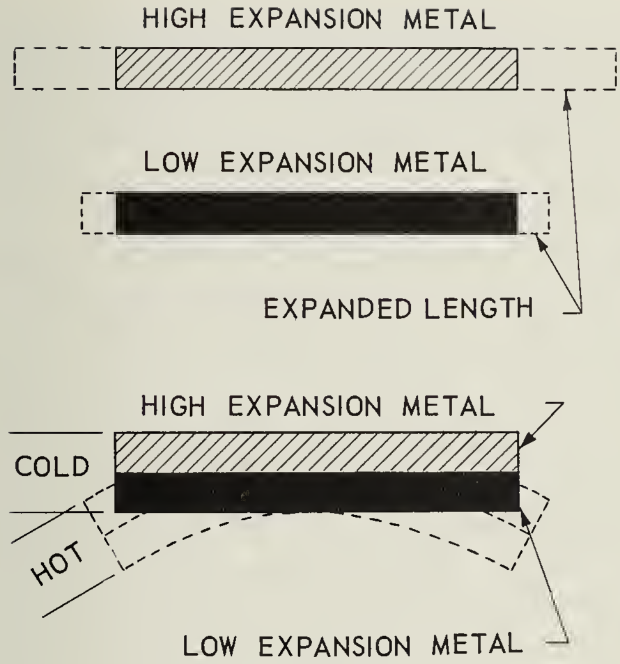


Figure 6-4. The working of bimetal strips.

expand at the same rate when subjected to the same intensity of heat. These basic facts have made it possible to produce many types of devices for the protection of motors and other appliance components.

To better understand the operation of bimetal devices, let us observe Fig. 6-4. The upper portion of the illustration represents two different strips of metal. One is a high-expansion metal while the other has a low expansion rate. The manufacturer of bimetals rolls two thin sheets of the different metals together while hot to form a single sheet. The sheets are then stamped into strips or disks according to specifications of the device manufacturer. When enough heat is applied to the bimetal, the strip warps always toward the low-expansion metal. If one end of the strip is anchored and a contact is attached to the other end adjacent to a stationary contact, a circuit can either be opened or closed at a predetermined temperature. Some bimetal strips and disks serve as current conductors, some actuate from radiant heat produced by a heating element, and in some instances the bimetal is affected by both the current it carries and radiant heat from an adjacent element.

There are quite a number of combinations that can be used to make bimetal. The combination used depends primarily on the method by which the strip is to be heated and the amount of warping required. For example, one of the most popular arrangements used today is made of invar and stainless steel. Invar is an alloy usually composed of 63.5 percent iron, 36 percent nickel, and 0.5 percent manganese. Invar has an exceptionally low rate of expansion and for this reason is used as one of the metals in most bimetal combinations. By comparison, stainless steel has a high rate of expansion.

Although numerous models of motor-protective devices involving bimetal are in appliances, we have selected two typical types to show the operation of an automatic reset.

The motor-protective portion of the current-type relay shown in Fig. 6-5 actuates by both the heat of the current and by radiant heat. When installed and in operation, all the current to the compressor motor passes from *A* to *B* through the two bimetal strips. If for any reason the motor circuit becomes overloaded, the

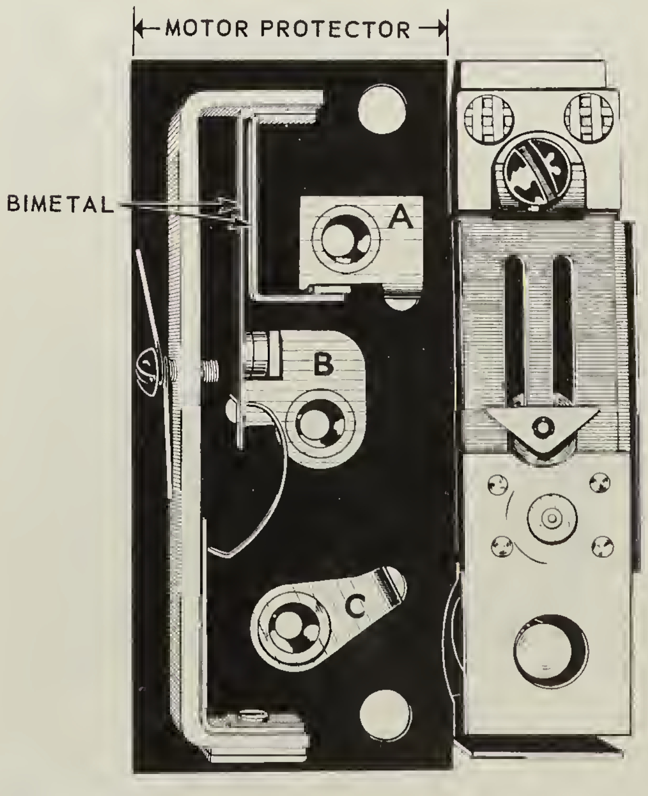


Figure 6-5. A typical current-type relay.

amperage through the two strips in series increases and the temperature of the bimetals increases proportionately. In addition, the heat of the shorter strip is radiated to the longer, which assists it in warping to open the contacts. As the strips cool, the movable contact arm assumes its normal shape and recloses the contacts. If the overload was of a temporary nature, the motor will continue its normal cycles. The length of time required for the protective device to open the motor circuit depends on the percentage of overload. The C-shaped spring serves as a toggle to ensure a quick opening and closing of the contacts. This prevents the contacts from excessive arcing and lengthens their life. All electric switches have either the toggle mechanisms or small magnets for this reason.

The two current-type relays illustrated and discussed in the preceding chapter also have bimetal motor-protector assemblies. The one illustrated on p. 88 actuates because of radiant heat produced by the heating element. The other illustrated on p. 88 actuates due to the heat of the current which the bimetal arm carries. The hook-shaped arm to which the upper end of the toggle spring is attached is also made of bimetal. It is called a *compensating arm*, and it shifts position slightly as the air temperature around it changes. This is necessary to provide the same motor protection at all room temperatures.

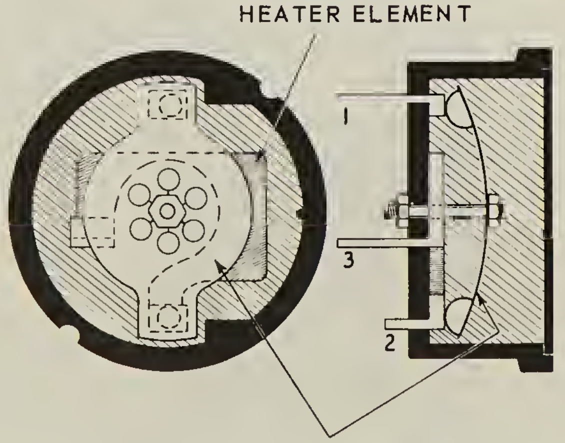


Figure 6-6. A typical disk-type motor protector with an automatic reset.

Figure 6-6 shows a disk-type motor protector, which is used on many room air conditioners. It is a small plastic cylinder mounted in a metal cup which is located on the dome of the compressor, where it is influenced by the temperature of the dome. As shown, there are three external blade-type terminals identified. Internally there is a saucer-shaped bimetal disk attached to a center post. The moving contacts are attached to the disk, which means that the disk also serves as a conductor of electricity supplied through terminals 1 and 2. Beneath the disk and attached to terminals 2 and 3 is a heating element. As described in the preceding chapter and illustrated on p. 90, this internal arrangement provides one path of current through the protector for cooling cycles and another path for heating cycles.

In operation, any condition that would cause an increase in amperage and dome temperature will also cause the temperature of the bimetal disk to increase. At a predetermined temperature, between 240 and 260°F, the disk warps to open the circuit. After the disk cools approximately 100°, it snaps to its normal shape and recloses the circuit.

There are several other applications for this type of protector. For example, many automatic-defrost refrigerators have one of these devices located adjacent to the freezing coil to serve as a limit switch. The purpose of the switch is to prevent the defrost heater from overheating during the defrost period. This is accomplished by opening the circuit to the heater when the bimetal disk reaches a temperature of 50°F. It automatically closes the circuit when the disk temperature again reduces to approximately 22°F.

A majority of external motors have time-delay types of protectors either built into the motor housing adjacent to the windings or embedded in the windings themselves. For most applications, these devices are of the automatic-reset type, in which the circuit is opened and closed at predetermined temperatures. These time-delay devices use bimetal as the actuating component.

Manual-reset type. Most manual-reset motor protectors are of the solder-pot type. In order to better describe the construction and operation of this type, a cutaway view of the device is illustrated in Fig. 6-7. As the name implies, the heart of the device is a solder pot containing an alloy or solderlike material having a nominal melting point of 205°F.

The solder, as a solid, holds a small ratchet wheel in a fixed position. When the push button is depressed a pawl, or metal finger formed in the spring-loaded sliding plate, engages one of the notches in the ratchet. This holds the contacts in their normally closed position and makes possible a circuit to the appliance motor.

The ratchet wheel and pot are attached to a temperature-sensitive strip of metal. Directly behind this is another strip of metal, which serves as a heater element and a conductor of current through the device. If, for any reason, the motor amperage increases, the temperature of the heater element also increases. Before the motor windings can reach an unsafe temperature, the radiant heat from the heater element causes the alloy in the pot to soften and the wheel becomes free to turn. The spring tension against the pawl then causes the ratchet wheel to turn, and the movement of the sliding plate opens the contacts and extends the push button further through the opening. Within a few minutes the alloy in the pot solidifies and permits reengagement of the pawl and ratchet when the reset button is pushed. Frequently, the protector is mounted to the end bell of the motor with the reset button extending through the frame.

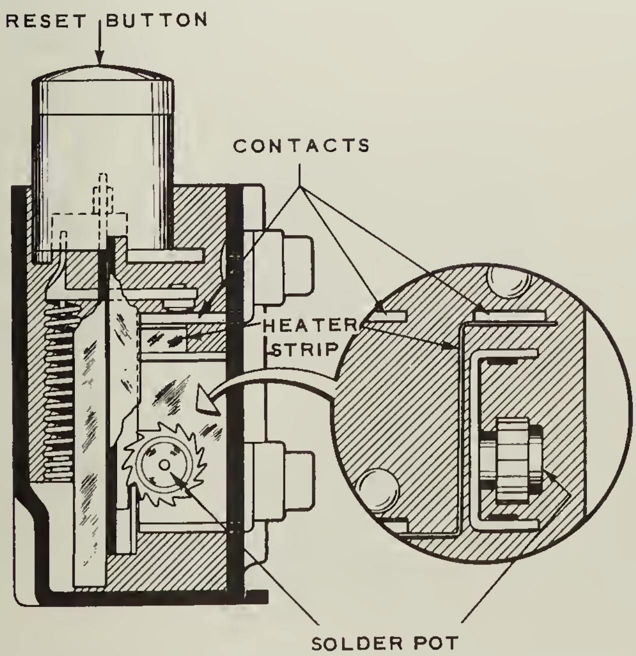


Figure 6-7. A manual reset motor overload protector (solder-pot type).

CONTROL DEVICES

Control devices are electric accessories which govern (in some predetermined way) the power delivered to any electric or appliance load.

In its simplest form the control applies voltage to, or removes it from, a single load. In more complex control systems, the initial switch may set into action other control devices that govern motor speeds, servomechanisms, temperatures, etc. In fact, all electric systems and equipment are controlled in some manner by one or more controls. A control is a device or group of devices which serves to govern, in some predetermined manner, the device to which it is connected.

Switches

Switches are used to control most appliance circuits. A switch may be described as a device used in an electric or appliance circuit for making, breaking, or changing connections under conditions for which the switch is rated. Switches are rated in amperes and volts; the rating refers to the maximum voltage and current of the circuit in which the switch is to be used. Because the switch is placed in series, all the circuit current will pass through it. Because the switch opens the circuit, the applied voltage will appear across it in the open-circuit position. Switch contacts should be opened and closed quickly to minimize arcing; therefore, switches normally utilize a snap action.

Many types and classifications of switches

have been developed. A common designation is by the number of poles, throws, and positions they have. The number of poles indicates the number of terminals at which current can enter the switch. The number of throws of a switch signifies the number of circuits each blade or contactor can complete through the switch. The number of positions indicates the number of places at which the operating device (toggle, plunger, etc.) will come to rest. Figure 6-8 presents the schematic diagrams of some often-used switches.

An example of the switch-position designation is a toggle switch which comes to rest at either of two positions, opening the circuit in one position and completing it in another. This is called a *two-position switch.* A toggle switch which is spring-loaded to the OFF position and must be held in the ON position to complete the circuit is called a *momentary-contact two-position switch.* If the toggle switch will come to rest at any of three positions, it is called a *three-position switch.*

Another means of classifying switches is the method of actuation, that is, *toggle*, *push-button*, *sensitive*, and *rotary* types. Further classification can be accomplished by a description of switch action such as *on-off*, *momentary on-off*, *on-momentary off*, etc. Momentary-contact switches hold a circuit closed or open only as long as the operator deflects the actuating control. Actually, switches are activated in several ways: manually, mechanically, by level, by pressure, and by heat; also there are the newer electronic switches, which we will not cover in this chapter.

Manually operated switches. Switches operated by hand, by a flip-flop motion (toggle switch), a turning motion (rotary switch), or a push-pull motion (push-button switch) are manual switches. Depending on their design, they can control one or more switch contacts (multiple switch). The switching mechanism or switch arms can be single-pole single-throw, simple on-off switches, or more complicated single-pole double-throw and double-pole double-throw switches (Fig. 6-9).

Mechanically operated switches are used in many applications. They are widely used because of their small size, light weight, and excellent dependability. For example, microswitches will open or close a circuit with a very small movement of the tripping device ($\frac{1}{16}$ in or less). They are usually of the push-button variety and depend upon one or more springs for their snap action. Actually, most push-button switches have one or more stationary contacts and one or more movable contacts. The movable contacts are attached to the push-

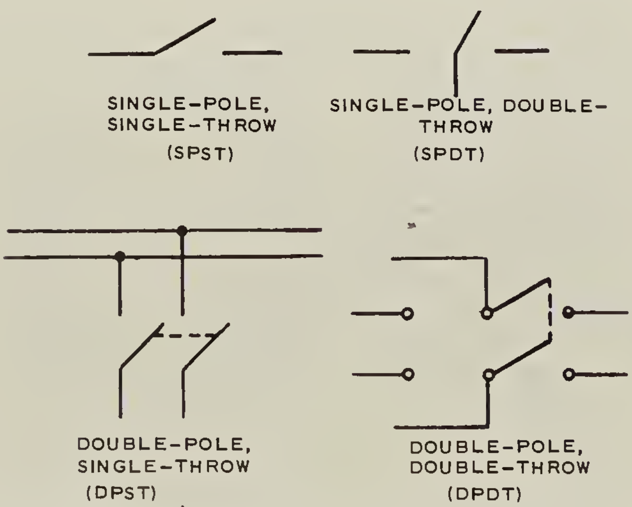


Figure 6-8. Schematic diagrams of commonly used switches.

AGITATE	SWITCH FUNCTION
HIGH	BU-O TO BU
MEDIUM	BU-O TO OR
LOW	BU-O TO GY-P
SPIN	
HIGH	R-W TO BU
LOW	R-W TO OR

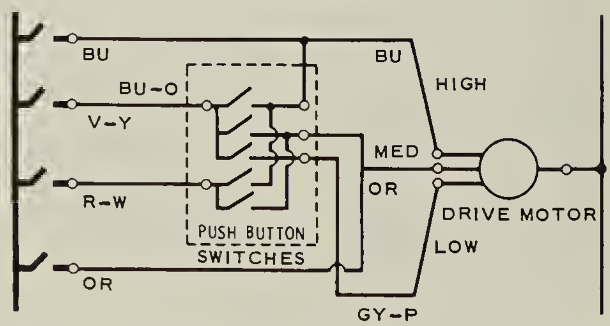


Figure 6-9. A complex speed-control switch as shown in a schematic drawing.

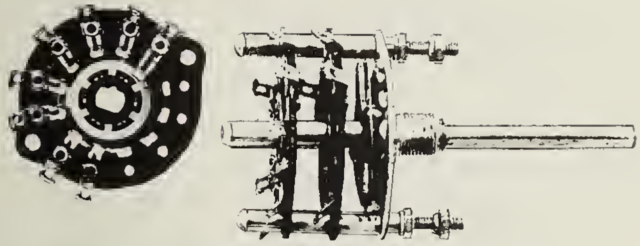


Figure 6-10. A rotary selector switch.

button by an insulator. This switch is usually spring-loaded and is of the momentary-contact type. These switches have many uses, such as indicator-light checks and circuit resets.

A rotary selector switch may perform the functions of a number of switches. As the knob of a rotary selector switch is rotated, the switch opens one circuit and closes another (Fig. 6-10). Some rotary switches have several layers of wafers. By adding wafers, the switch can be made to operate as a large number of switches.

Some manual switches, such as doorbell switches, are closed only while they are being pushed (momentary contact). Others, such as many fluorescent-lamp switches, make a set of momentary contacts while being pushed or turned and another set of contacts when released.

Mechanically operated switches. Mechanically operated appliance switches are actuated by various methods. For instance, *magnetic switches* are actuated by a permanent magnet or electromagnet. *Mercury switches* are actuated by switch level. *Pressure switches* are actuated by utilizing the pressure of air or fluids. *Centrifugal switches* are actuated by centrifugal force from the speed of a spinning or turning shaft. *Float switches* are actuated by varying liquid levels on which a float rides. *Thermal switches* are actuated by temperature. *Timer switches* are actuated by a clocklike mechanism. These are the most common methods of actuation, but as you read the three later volumes in this series, you will find other methods of operation of mechanical switches. For now, however, let us look at the basic principles of the more common ones just mentioned.

Magnetic switches operate by the action of a magnetic field. This magnetic field can be from a permanent magnet or from an electromagnet. A permanent-magnet switch is used to control

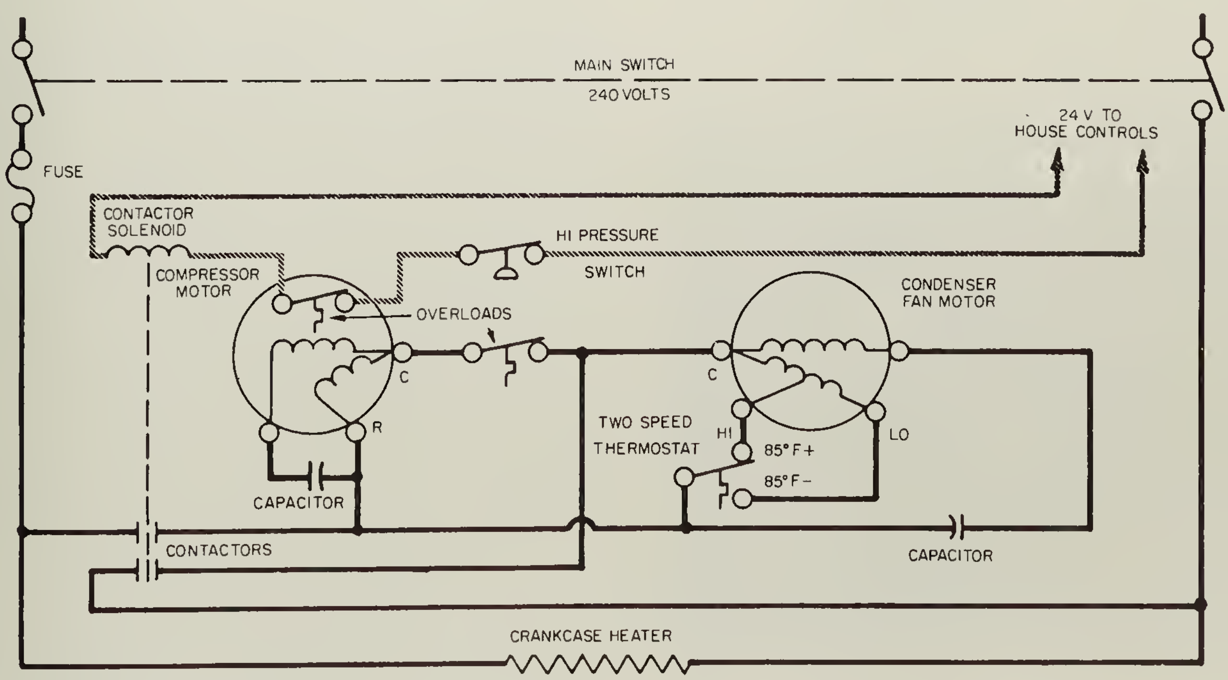


Figure 6-11. A typical control circuit for a heating/air-conditioning system.

the lights on some refrigerators. A permanent magnet attached to the door of the refrigerator attracts a soft-iron switch arm, opening the switch contacts and the circuit to the lights. As the door is opened, the permanent magnet swings away from the switch arm, causing it to lose its magnetic effect on the arm and closing the switch to the light circuit.

We have discussed some good examples of magnetic switches operated from the effect of an electromagnet. Both the voltage- and current-type starting relays used on most domestic refrigeration systems operate by this principle. Electromagnetic switching is most frequently used to control high-voltage components, such as a 240-V central air conditioner with a low-voltage, 24-V room thermostat circuit. The contactor and relay coils (electromagnetic switches) are energized with 24 V from the room thermostat in the typical heating/air-conditioning circuit of Fig. 6-11. The 24-V relay coil controls the switch to the 120-V furnace blower while the 24-V contactor coil or solenoid controls the contactors (switches) to the 240-V air conditioner and condenser fan motors.

Mercury switches are activated by the switch level. The switch in the 24-V room thermostat just discussed is a prime example. A small, sealed glass tube (Fig. 6-12) with a drop of mercury inside and a set of wires extending into the tube at each end make up the mercury switch. As the tube tilts, the mercury runs to the lower end, covering the ends of the exposed wires. The electric circuit containing these wires is completed through the mercury. A similar switch is used to stop the spin of many automatic washers when the top lid is raised.

Pressure-operated switches usually have Bourdon tubes, syphons, or diaphragms against which fluids or air operate to actuate the switch. For instance, most dishwasher overflow switches are pressure-activated. In some, the pressure or weight of the water on a rubberlike diaphragm activates a switch and opens the circuit to the water-fill valve. On others, the water level causes a float to rise that reduces the pressure on a spring-loaded arm and causes the switch to open the circuit. (This is an example of a *float switch.*) The water level in many washing machines is controlled in a similar manner. Air

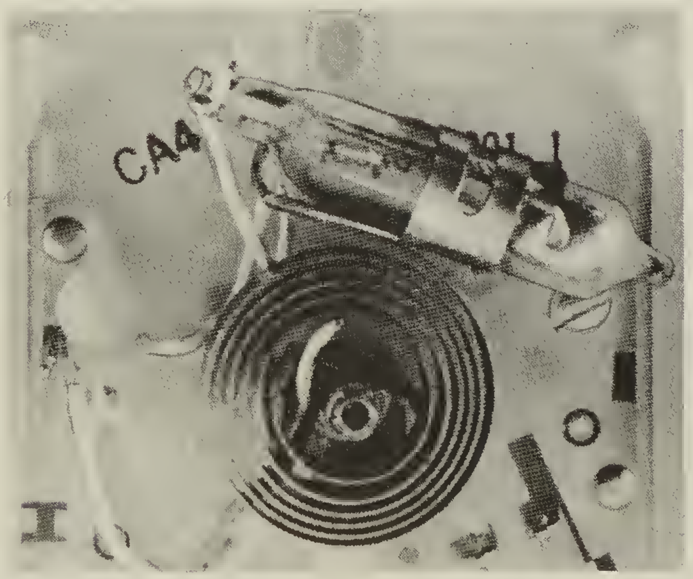


Figure 6-12. The mercury switch in a room thermostat.

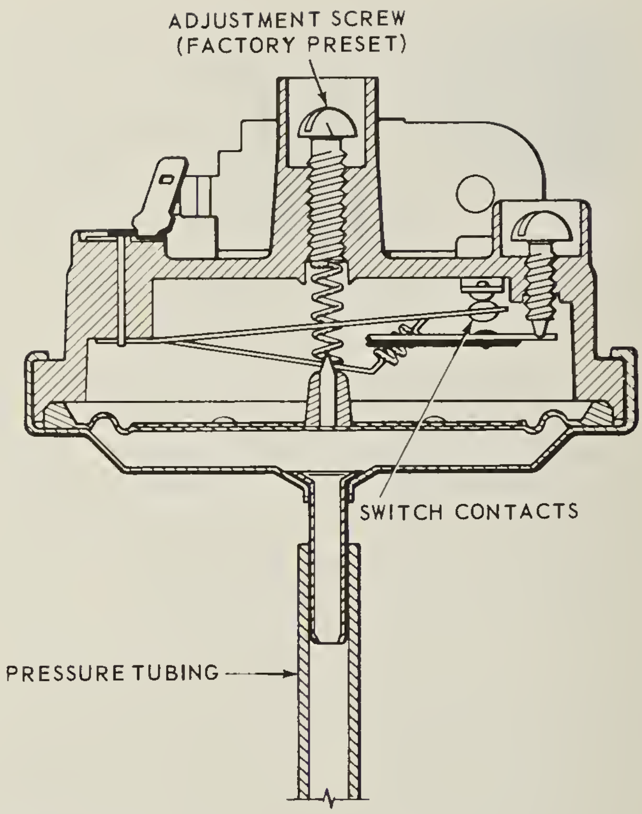


Figure 6-13. A typical water-level switch.

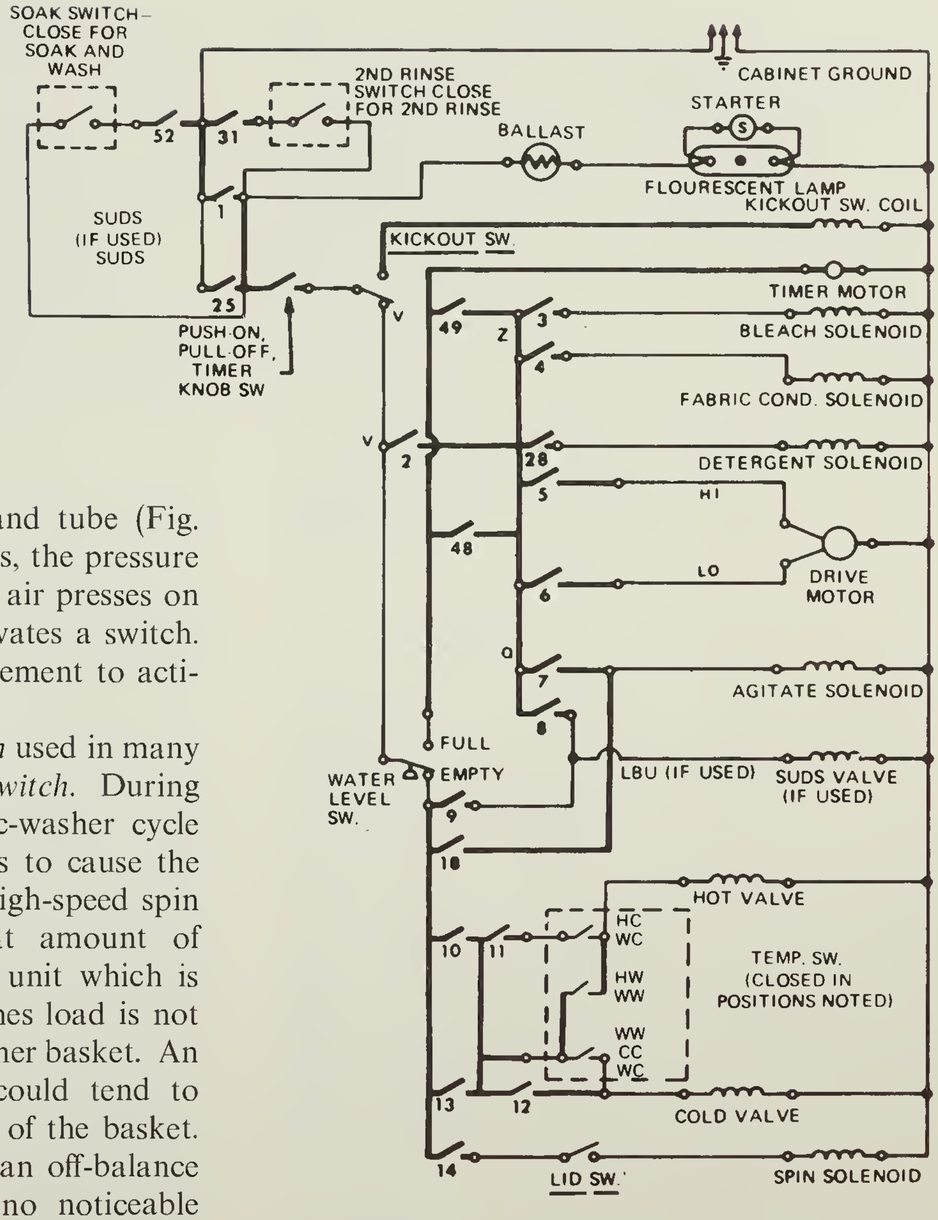


Figure 6-14. The wiring diagram showing the lid switch and kickout switch in an automatic washer.

is trapped in a pressure dome and tube (Fig. 6-13). As the water in the tub rises, the pressure becomes greater in the tube. This air presses on a rubberlike diaphragm that activates a switch. Other washers use a float arrangement to activate the water-level switch.

The *off-balance* or *kickout switch* used in many clothes washers is a *centrifugal switch*. During the wash period of an automatic-washer cycle there is comparatively little stress to cause the unit to move. However, in the high-speed spin (500+ r/min), there is a great amount of centrifugal force built up in the unit which is particularly noticeable if the clothes load is not evenly distributed around the washer basket. An item such as a heavy blanket could tend to concentrate the load on one side of the basket. The machine is designed to take an off-balance condition of $3\frac{1}{2}$ to $4\frac{1}{2}$ lb with no noticeable effect. More than this can result in centrifugal stresses that could cause the unit to move or "walk." Most automatic washers are equipped with an off-balance or kickout switch that stops the unit and causes a buzzing sound at any point in the cycle if an off-balance condition occurs.

As shown in the schematic diagram, Fig. 6-14, the master single-pole single-throw timer-knob switch (push-pull switch) is in series with the single-pole double-throw kickout switch and the kickout-switch coil or solenoid. When an unbalanced condition exists, the kickout switch closes the circuit to the kickout solenoid, which in turn holds the kickout switch in the OFF-BALANCE position. This breaks the electric circuit to all the washer's functional parts, stopping the cycle. The user then must redistribute the load more evenly in the washer basket, pull the timer dial out to de-energize the kickout solenoid and allow the kickout switch to reset, and then push the timer dial in. This again closes the circuit to the functional parts of the unit and the machine starts at the point where its cycle was interrupted.

Many switches are activated by heat and are generally called *thermal switches* or *thermostats*.

There are two general principles of control: bimetal and hydraulic.

Different metals expand and contract at different rates. When two differing metals are bonded together, they form a bimetal strip. As heat is applied, the two strips expand at different rates, causing the bimetal strip to warp, or bend, toward the side that has the smaller expansion rate (Fig. 6-4). This movement is used to operate switches. The room thermostat or fan-limit switches on furnaces are good examples of adjustable bimetal thermostats. Most fixed-temperature thermostats used on appliances such as dryers, refrigerators, air conditioners, motor temperature controls, etc., use this principle.

A good example of the bimetal-type switch is the temperature-limit control which is employed to prevent serious overheating in the event that a malfunction from a clogged lint screen, blocked exhaust, overloaded drum, etc., should occur in a dryer. At a predetermined temperature the contacts in the limiter will open and disconnect the power from the heat source. The limiter switch is a snap-action bimetal switch designed to respond to temperature change. The switch is mounted to the heater or burner housing (Fig. 6-15). In the event that air flow is reduced or there is an inoperative thermostat, the operation of the limit switch is as follows:

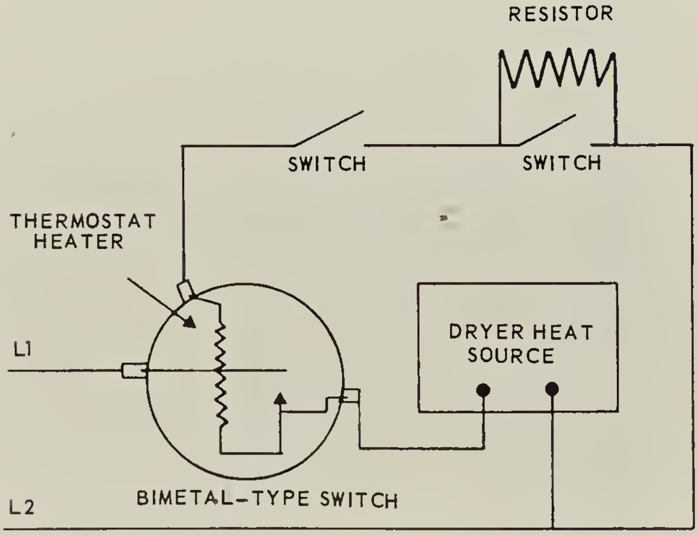


Figure 6-15. A snap-action bimetal switch.

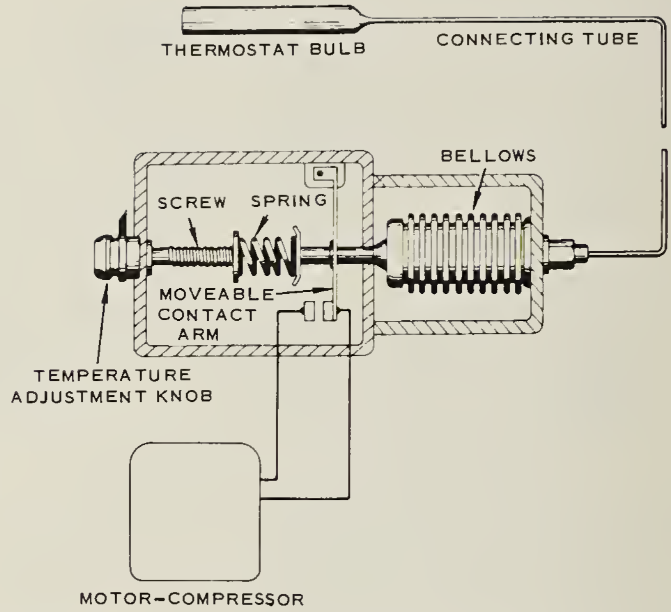


Figure 6-16. A heat-actuated hydraulic switch frequently used in refrigerator thermostat assemblies.

As the burner housing is heated to temperatures above normal, the bimetal disk of the limit switch becomes heated to its operating temperature and it responds to open the heat-source circuit. After the contacts have opened, the housing will begin to cool off. The limit-switch bimetal disk will also cool until the disk again responds by snap action to close the heat-control circuit. This cycle will repeat until the timer completes the programmed time.

Heat-actuated hydraulic switches (Fig. 6-16) use a sealed hydraulic system to operate a switch. Liquids, like metal, expand as they heat. The sealed hydraulic system is generally filled with a liquid, such as oil, mercury, freon, etc.; however, it can be filled with a gas—the principle of operation remains the same. A sensing area of the system "feels" the temperatures that require control. This sensing area is connected by a small tube or capillary to a bellows which is part of the switch assembly. The sensing area, capillary, and bellows are filled with liquid and form the sealed hydraulic system. As the sensor is heated or cooled, the expanding or contracting liquid flowing through the capillary tube expands or contracts the bellows. This movement of the bellows actuates the switch in

the thermostat. This type of control is often designed so that it is adjustable over a temperature range. For example, a refrigerator thermostat may be adjustable from 32 to 45°F, or an oven thermostat may be adjustable from 200 to 550°F, etc. This is generally accomplished by spacing the thermostat switch contacts by turning the thermostat dial.

Timer switches are used in most clothes washers, dryers, ranges, and refrigerators. With the exception of washer timers, these switches are activated by a timer motor that slowly turns a cam. Spring-loaded switch arms close as the cutout in the cam allows them to drop and open as the turning cam forces them open. The particular shape of each cam varies with the number of switch contacts it controls and the length of time each switch contact is to remain closed. Figure 6-17 illustrates a very simple cam that controls one switch contact. In Fig. 6-17A this switch is closed. In Fig. 6-17B the switch contact has now opened. This happens because the cam in this timer has an advancement of six degrees (6°) every 60 s. The cutout portion of the cam which closed the switch in Fig. 6-17A is twelve degrees (12°), therefore, the cam-switch contacts are closed for 2 min (or two increments)

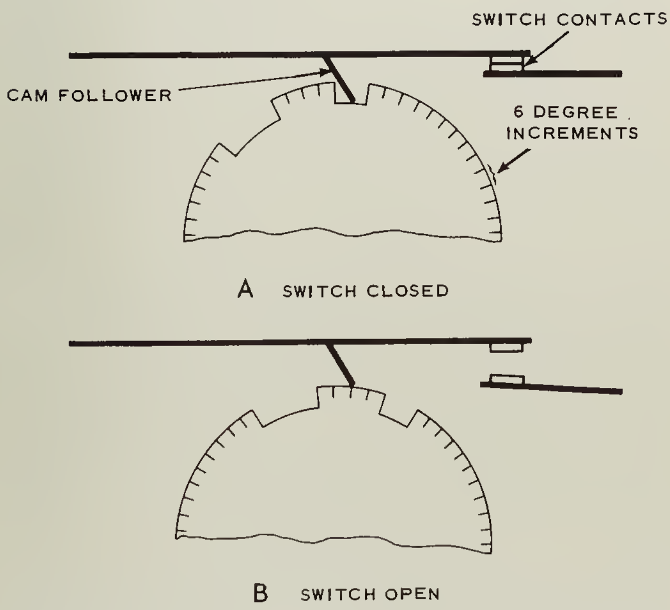


Figure 6-17. A simple cam switch in operation.

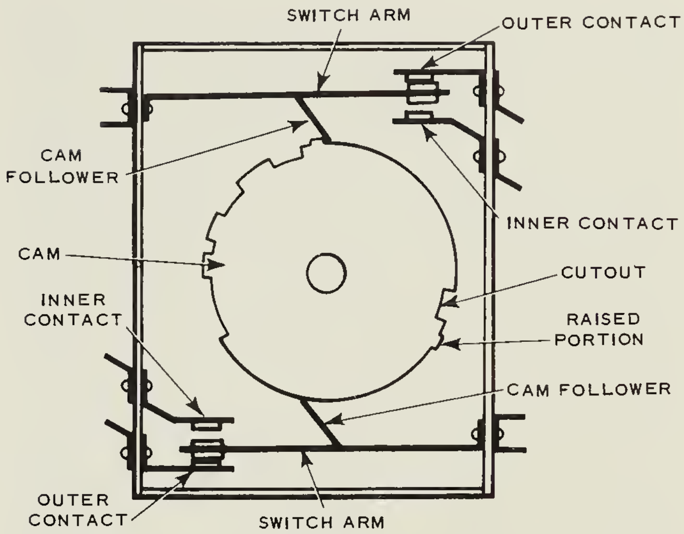


Figure 6-18. A typical multiple-function cam that is often employed in an automatic washer.

during this cycle. As the timer advances, the switch contacts will once again close when the second cutout reaches the switch. Here, the switch will be closed for four increments (24°).

Figure 6-18 illustrates a more complicated cam. This cam is designed to control two switch arms, each having dual contacts. You will note that this cam has raised portions as well as cutout sections. The raised portions force the cam switch arm against the outer contact, and the cutout sections allow the cam switch arm to make contact with its inner contact.

Washer timers, because of the greater number of switch arms and cycles controlled, are more complex and use an intermediate spring-wound escapement to move the switch cams a designed number of degrees rapidly as the escapement spring unloads. The timer motor slowly winds the escapement, storing energy in the stretched spring. Incidentally, most timer motors are of a synchronous type, similar to those used in electric clocks (see p. 97).

In addition to the multiple-cam switches, there is an ON-OFF switch built into the timer unit which is operated by pushing and pulling the timer dial. When the timer dial or knob is pushed in toward the timer body, the switch is closed. On some washer models this action is

reversed; the switch is closed when the timer knob is pulled out.

Maintenance of switches. While the switch itself is relatively simple to check, it sometimes offers difficulty in maintenance because of its location in inaccessible places. After a visual inspection of the connections and the switch, a continuity test will indicate any malfunctions. When the switch mechanism is found to be defective, it normally is not repairable and therefore should be replaced.

When enclosed switches are used, failure to seal properly around cable openings may cause difficulty. Altitude changes permit "breathing" of moist air into enclosures with improperly sealed cable openings, and the moisture in the air may condense within the switch enclosure. The condensation can short across the switch terminals and can corrode the switch actuators in a manner that may make them inoperative. This difficulty can be corrected by carefully sealing the openings or by using hermetically sealed switches. Hermetically sealed switches will also prevent dust and dirt from reaching the contacts and thereby reduce the possibility of high resistance and open circuits.

Some switches are damaged during installation, particularly those with plastic housings. Proper care in installing or replacing plastic-enclosed switches will eliminate this.

Some switch assemblies are equipped with adjustments which enable them to operate at a preset time or pressure. Caution should be exercised in making these adjustments; if they are not accurate, damage can result.

RELAYS

As previously indicated, relays are actually automatic switches which open or close an electric circuit according to the requirements of the system on which they are installed.

The relays that are discussed here, like those in the preceding chapter, have a solenoid coil and iron core energized by alternating current. While there are a great many uses for relays in appliance circuits, we discuss only two typical applications.

The first is the *starting relay* shown in the dishwasher schematic diagram, Fig. 6-19. While this relay is energized for only 45 s each washing load, it performs an important function. Its purpose is to start the timer motor when the START button on the washer door is pushed. This permits the timer motor to wind the escapement spring in the timer so that it can progress from the OFF position to start its sequence of operations.

To understand the need for the relay, it should be remembered that the last advance of the timer dial at the end of the drying period stops the timer motor. At this time, the escapement spring is completely unwound. When the button is pushed to start the next cycle, a circuit through the relay solenoid coil is completed. This closes the relay contacts to complete a circuit through the timer motor. At the end of 45 s, the escapement spring is rewound and the timer advances to close contact No. 2. At this instant, the relay

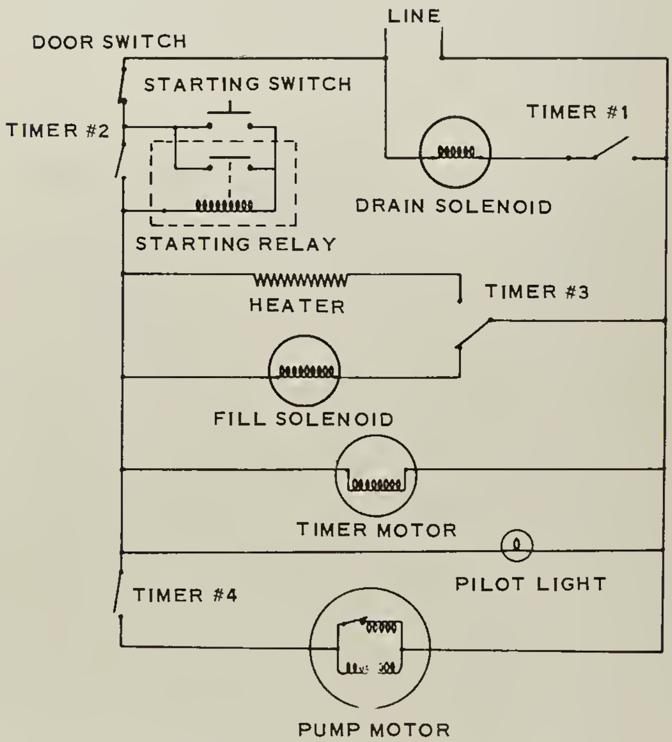


Figure 6-19. The operation of starting relay in an automatic dishwasher.

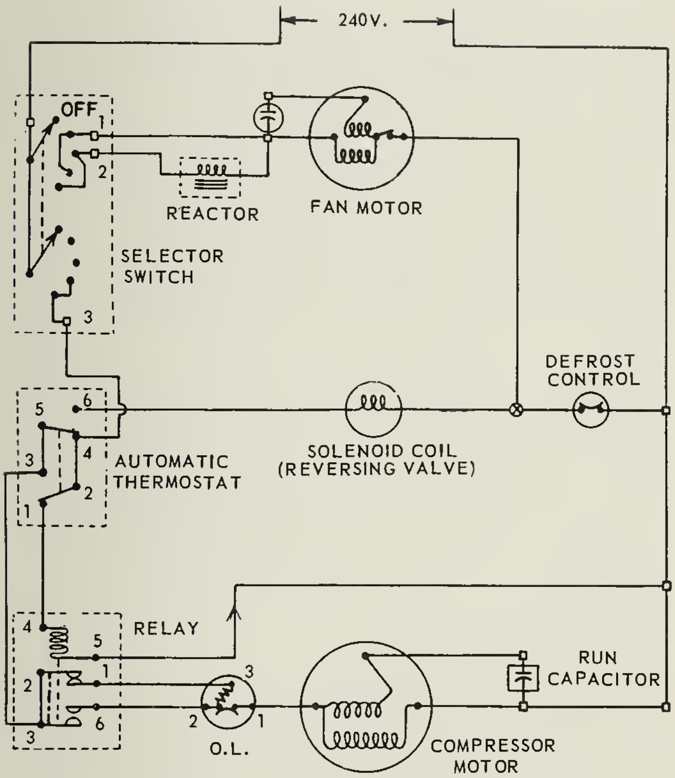


Figure 6-20. A protector relay in a typical air conditioner circuit.

contacts open, and remain so until the button is pushed at the beginning of the next washing load. The reason the relay contacts open is one of the basic laws of current flow: Current always flows through the path of least resistance. Since the resistance of the relay coil is much greater than that through the timer No. 2 contact, the coil loses its current and magnetic field. The relay contacts cannot, therefore, remain closed.

In addition to its application in a dishwasher, this basic law of current flow is frequently applied to the design and operation of other types of equipment.

As shown in the schematic drawing, Fig. 6-20, the second type of relay we wish to discuss is the *protector relay*, which is so named because of the role it plays in providing adequate motor protection. In this case, it protects the compressor motor in a room air conditioner designed to provide both cooling and heating. The relay coil is designed for the same line voltage as the compressor motor, either 240 V or 208 V.

In spite of the fact that the compressor motor operates during both the cooling and heating cycles, the operating load and consequent amperage draw during the heating cycle is somewhat less than that during the cooling period. In order to ensure proper overload protection for the compressor motor for heating periods as well as for cooling, the motor protector, located on the dome of the compressor housing, is designed to provide either of two paths of current to the motor. The protector relay is used to automatically direct the current through the proper path according to the setting of the automatic thermostat on the unit. This can be better understood by noting the schematic wiring diagram.

When the thermostat is in the cooling position and the compressor is operating, we note that there is a circuit through the protector-relay coil to the other supply line. The resulting magnetism attracts the armature, which closes the lower set of relay contacts. This provides a circuit to the motor-protector terminal No. 2. From here it takes a normal path through the motor protector and windings to the other supply line. Higher operating pressures, present during the cooling cycle, are accompanied by higher amperage through the protector and windings. The protector has been selected to give proper protection under these circumstances.

When the thermostat is in the heating position and the compressor is operating, no current is flowing through the protector-relay coil. This means that the upper set of contacts is closed. The current to the motor now takes another internal path through the motor protector from terminals No. 3 to No. 2 to No. 1. An internal heating element is now in series with the cooling-cycle protector. This adds sufficient heat to the device to compensate for the reduced amount of current being utilized by the compressor motor during the heating cycle. The motor therefore receives the same protection as that provided during the cooling period.

Maintenance of Relays

The relay is one of the most dependable electromechanical devices in use, but, like any

other mechanical or electrical device. relays occasionally wear out or become inoperative for one reason or another. Should relay inspection determine that a relay has exceeded its safe life. the relay should be removed immediately and replaced with another of the same type. Care should be exercised in obtaining the same type replacement. because relays are rated in voltage, amperage, type of service, number of contacts, continuous or intermittent duty, and similar characteristics.

For spotting potential relay trouble during preventive maintenance, the following guides are suggested: Check for charred or burned insulation on the relay and for darkened or charred terminal leads coming from the relay. Both of these indicate overheating. If there is even a slight indication that the relay has overheated it should be replaced with a new relay of the same type. Occasionally, relay trouble is not the fault of the relay at all, but is due to overheating caused by the power-terminal connectors not being tight enough. This should always be checked during preventive maintenance.

SOLENOID VALVES AND DEVICES

The invention and development of solenoid valves and devices has had a tremendous influence on the design and operation of equipment produced by numerous industries. It might be said that only because of solenoid valves and devices are many of the automatic features in most of our modern appliances possible.

A solenoid is a device used as a means for converting electric energy into mechanical motion. It consists of a coil of enamel-coated wire wrapped around a nonmetallic bobbin and supported by a laminated iron field or a steel frame. When electric current flows through a coil of wire, a magnetic field is produced in the center of the coil. When the solenoid coil is energized it acts like a magnet.

Some solenoids are equipped with a free-moving armature or plunger which is so assembled that it can be easily moved in and out of the center of the coil. When the solenoid is energized, this plunger is pulled into the center of the coil by the magnetic attraction. When current stops flowing through the coil, the magnetic force ceases and the plunger is moved back to its original position (by gravity or spring action). Other solenoids are equipped with a stationary core which pulls a metal armature or plate against the end of the solenoid when current flows through the coil. The armature or plate is usually returned to its original position by spring action when the solenoid is de-energized.

Solenoid Valves

A typical and representative type of solenoid valve is shown in Fig. 6-21. In most instances. the main body of the valve is made of brass and has an inlet and outlet connection for the passage of either liquid or vapor, depending

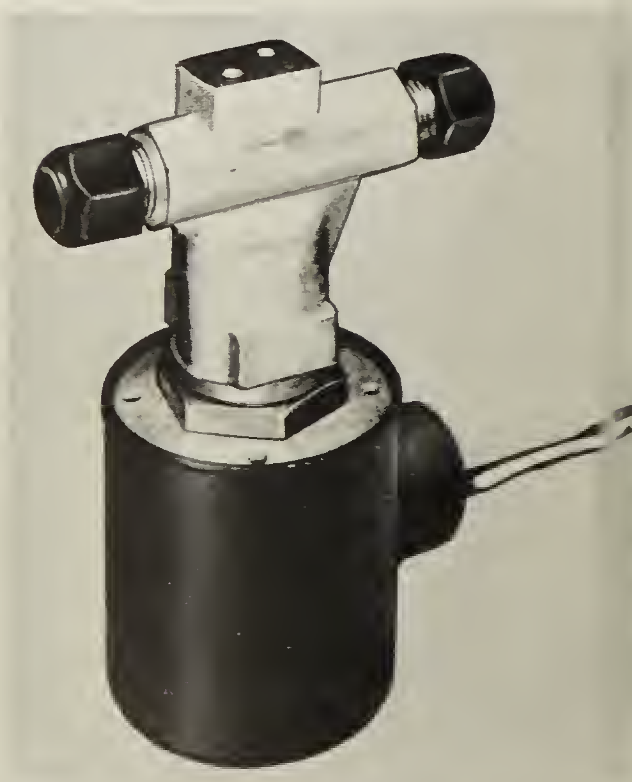


Figure 6-21. A typical and representative type of solenoid valve.

upon the application. On top of the valve body is a solenoid coil with two external leads for connecting it to the source of current. Inside the coil is a brass sleeve which is sealed at the upper end and attached to the valve body to form a leakproof assembly. Inside the sleeve is a movable iron core or plunger, the lower end of which is either needle-shaped or is attached to a movable seat which engages an orifice in the valve body.

Some valves are designed to close the orifice when the solenoid coil is energized, while most valves are normally closed and only open when the coil is energized.

The solenoid coil, like all electric devices, must be designed for the same current characteristics as the line current to which it is connected. The nameplate on most valves lists the voltage, cycle, and wattage consumed. It also usually lists the maximum pressure difference, between both sides of the valve seat, at which the valve will open.

To help you to understand the operation of a solenoid valve, the basic principles are illustrated in Fig. 6-22. Observe the magnetic lines of flux produced when the coil is energized. In this instance, the force is in an upward direction, through the center of the coil and the sleeve, as represented by the heavy lines. This establishes an N pole at the top and an S pole at the bottom. If an iron core is placed at the bottom of the sleeve, lines of flux will be caused to pass through it, making the upper end of the core N and the lower end S. If the core is free to move, it will be magnetically attracted into the sleeve and will stop at the exact vertical center. In other words, it will actually float in the center of the sleeve. The weight attached to the core represents an important factor in the design of the coil. The greater the distance the core has to travel, and the greater the pressure that must be overcome, the stronger must be the field of flux. This is determined by the size of the wire and the number of turns in the coil.

Now let us discuss some practical applications of solenoid valves. The valve illustrated in Fig. 6-23 is one that is used on many models of ice cube makers. The view on the left shows the internal arrangement of the components in the

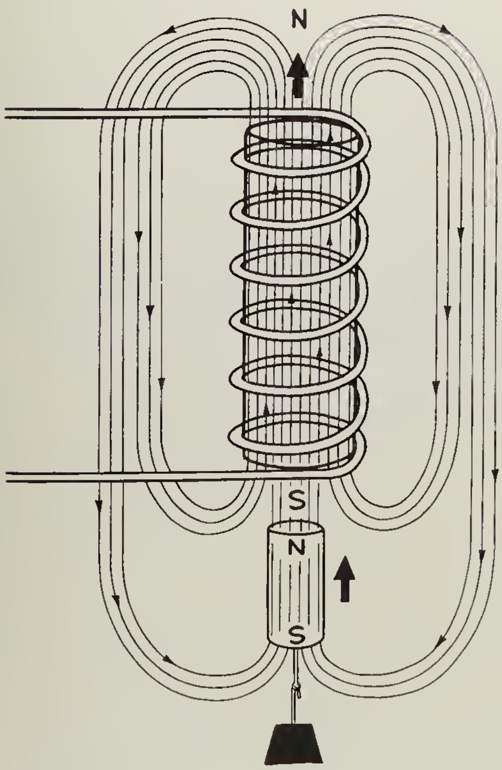


Figure 6-22. The basic principle of a solenoid valve.

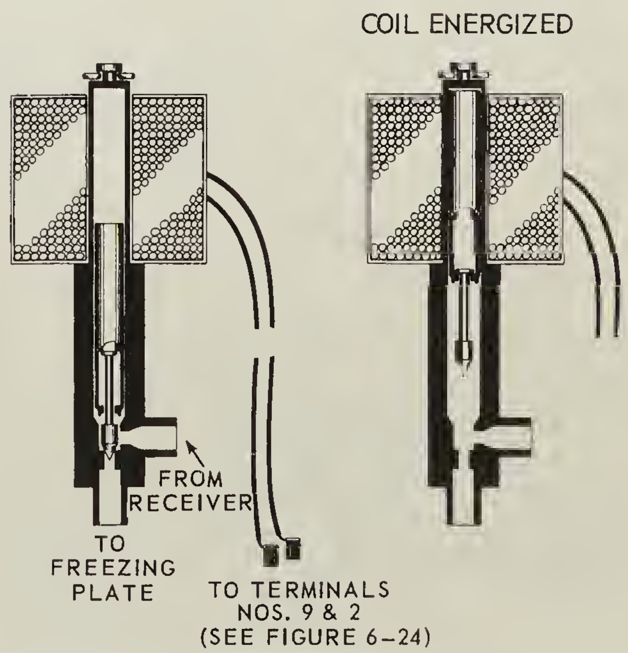


Figure 6-23. A typical hot gas solenoid valve used in many models of ice cube makers.

normally closed position. The view on the right shows the position of the plunger when the coil is energized. When the circuit through the coil is opened, the plunger instantly loses its magnetism and returns to its normal position. Valves of this type must be installed in a vertical position as illustrated. On other applications, where the valve cannot be installed in this manner, a spring is used between the end of the plunger and the sealed end of the sleeve. When the coil is de-energized, the spring tension causes the valve to close even though it has been installed in an inverted position.

Due to their function in the system, the solenoid valves used on many ice cube makers are called "hot gas" valves. The one illustrated is installed in the high-temperature vapor line between the condensing-unit receiver and the low-pressure side at the freezing plate. This provides a bypass between the high- and low-pressure sides of the system.

The solenoid coil receives its current through a set of contacts in the ice-thickness thermostat, which has a double-throw switch, as indicated in the schematic wiring diagram shown in Fig. 6-24. During the freezing period, the solenoid valve remains closed. When the ice slab has frozen to its predetermined thickness, the thermostat opens the circuit to the water-circulating-pump motor and closes the circuit to the solenoid coil. The valve plunger is pulled from the orifice seat and hot gas flows through the valve to the refrigerant passes in the freezing plate. This provides sufficient heat to loosen the ice slab from the plate and permits the slab to slide onto the cutting grids. This requires only a minute or so of time. After the ice slab is released from the plate, the thermostat soon opens the circuit to the solenoid coil and closes the circuit to the pump motor to start the next cycle. The solenoid coils on the majority of ice cube makers are designed for 120-V current and are therefore connected into the high-voltage circuit.

Another model of solenoid valve is frequently used on models of room air conditioners designed to provide both cooling and heating. The valve is an integral part of the reversing-valve assembly, a cutaway view of which is shown in Fig. 6-25. The solenoid valve plays a significant

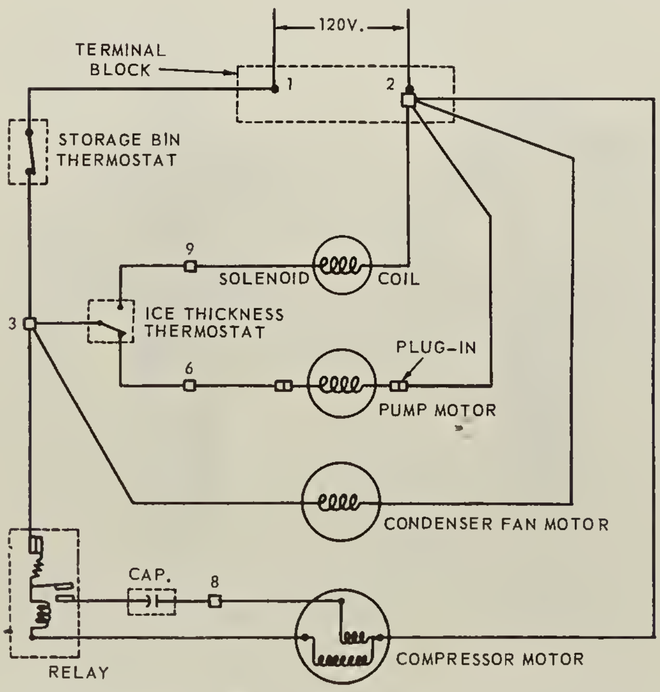


Figure 6-24. The high voltage circuit schematic diagram of a typical ice cube maker.

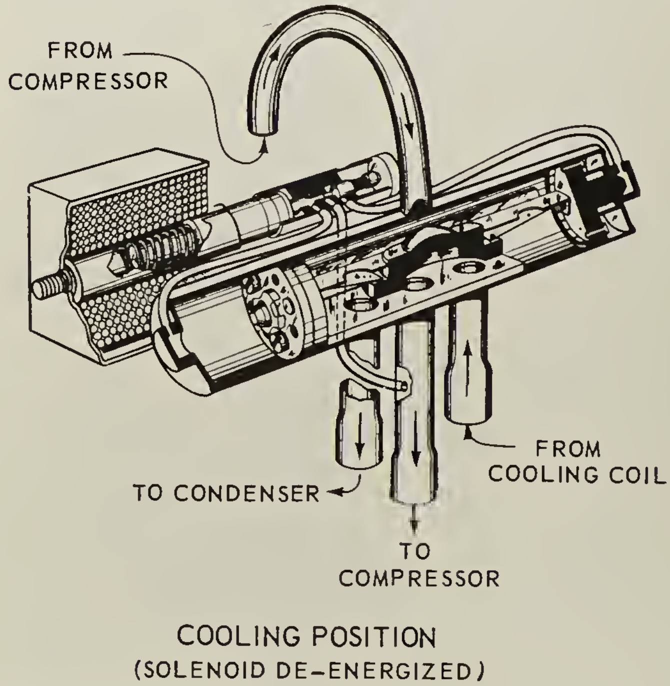


Figure 6-25. A reversing valve and solenoid assembly used in many air conditioners.

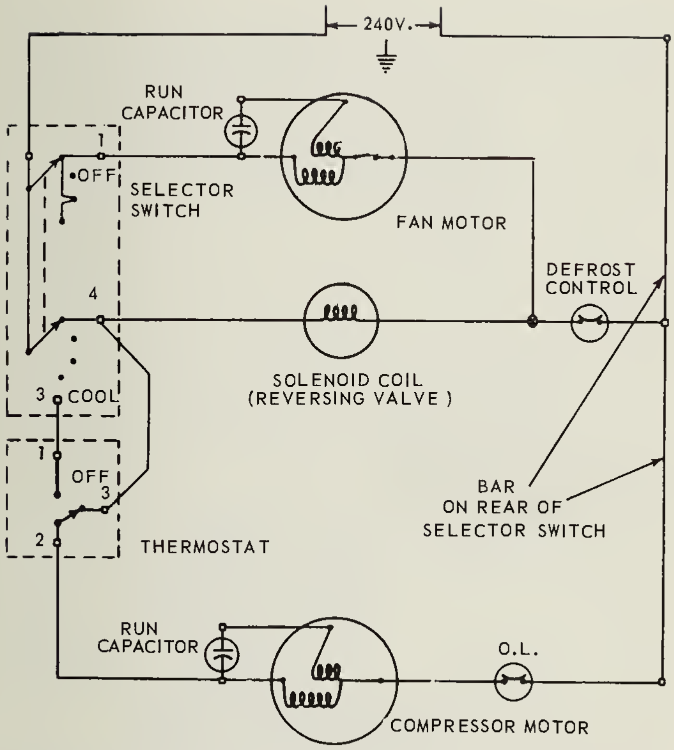


Figure 6-26. The electric circuit for the air conditioner heating cycle.

role in making it possible for these units to perform their dual function. It serves as a pilot to actuate the reversing valve. It can be observed that the solenoid valve has a double orifice, that it has two seats, and that the plunger is backed by a spring. The coil is de-energized during the cooling period, and the extension on the end of the plunger pushes against the opposing seat. This provides a path through the valve for vapor pressure, which establishes and maintains the proper direction of vapor flow through the reversing valve. In the position illustrated, the compressed vapor from the compressor is directed into the condenser to permit the cooling coil to remove heat from the room.

When the thermostat is in the heating position, the solenoid coil is energized. This attracts the plunger, permitting the opposing seat to close and providing an alternate path through the solenoid and reversing valve. Since the reversing valve has shifted in the opposite direction, the compressed vapor from the compressor is directed into the cooling coil. The condenser now becomes cold and the cooling coil becomes hot. The fan blows the heated air into the room and the cold air is discharged to the outside. The electric circuit for the heating cycle is shown in Fig. 6-26.

Most gas dryers incorporate a solenoid valve which is used to control the operation of the gas burner. This solenoid valve is part of a combination valve assembly which also provides gas pressure regulation and safety shutoff in case of pilot or ignition failure. Figure 6-27 shows a cutaway view of the combination valve used with the electric ignition system. In this assembly the main gas valve is controlled by the thermostat to provide gas to the burner whenever heat is required. The cycling gas valve serves as a safety shutoff in the event that the electric ignition system should fail or the flame on the burner should be extinguished for some reason. A holding resistor is placed in series with the cycling-valve coil. This restricts the flow of current to the coil so that the valve will not open unless full line voltage is supplied by the properly operating electric ignition system. Once opened, the valve will remain open even with the resistor in series with the coil. This feature provides protection against interruptions in line voltage which would momentarily close the main valve and the cycling valve and extinguish the flame. The cycling-valve coil in series with the resistor would not permit the valve to reopen until the electric ignition system had cooled and reset itself for normal opera-

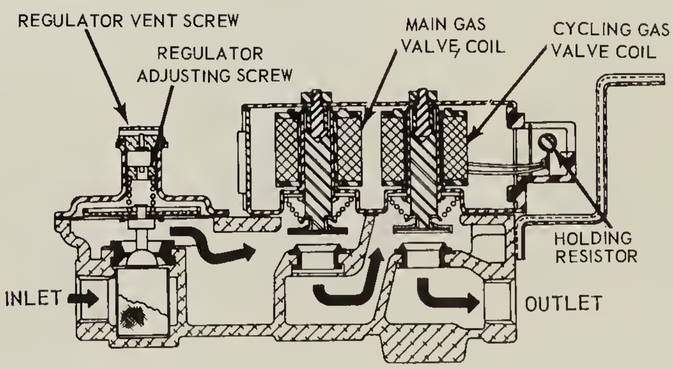


Figure 6-27. A typical safety shutoff solenoid valve.

tion. At that time line voltage would be supplied to the cycling-valve coil by the ignition system, and normal burner operation would resume.

The solenoid valves that we have discussed are used to control the flow of vapors. Similar valves are suitable for controlling the flow of liquids. For example, many clothes washers and dishwashers use solenoid valves to start and stop the flow of water into the washers. The clothes washers have two valves in one assembly: one for the hot water, and the other for the cold water. This permits the mixing of the two to obtain the proper rinse-water temperature. The dishwasher has one solenoid valve for hot water only.

Solenoid Devices

The term *solenoid devices* is used to identify devices which operate on the basic principle of solenoid valves but do not directly control the flow of liquids or vapors. In other words, these devices have moving cores or plungers which are connected to levers or movable arms. For example, the drain valve on most dishwashers, except the portable models, is actuated by a solenoid located in front of the motor.

Another application for this type of device is illustrated in Fig. 6-28. This shows a phantom view of the suds-serving assembly used on certain models of clothes washers. At a certain point in the timer sequence the solenoid is energized, the core is attracted to the coil, and because of the linkage and connecting arm, the internal valve shifts position. This permits a small water pump to force the wash water from the tub into the suds container. When the solenoid is not energized, the water flows through the valve either from the tub to the drain or from the suds container, through the pump, and to the tub, depending upon the dictates of the timer.

Although there are numerous applications for

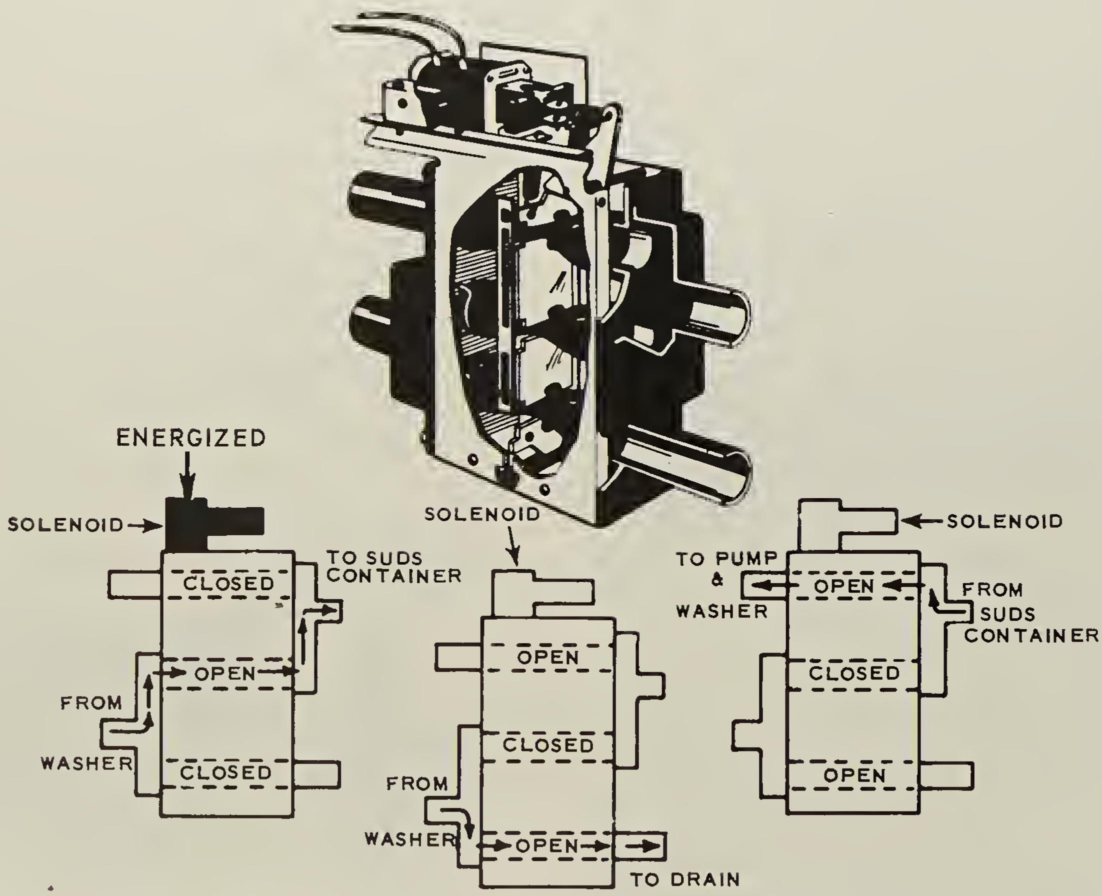


Figure 6-28. A phantom view of the suds-serving assembly.

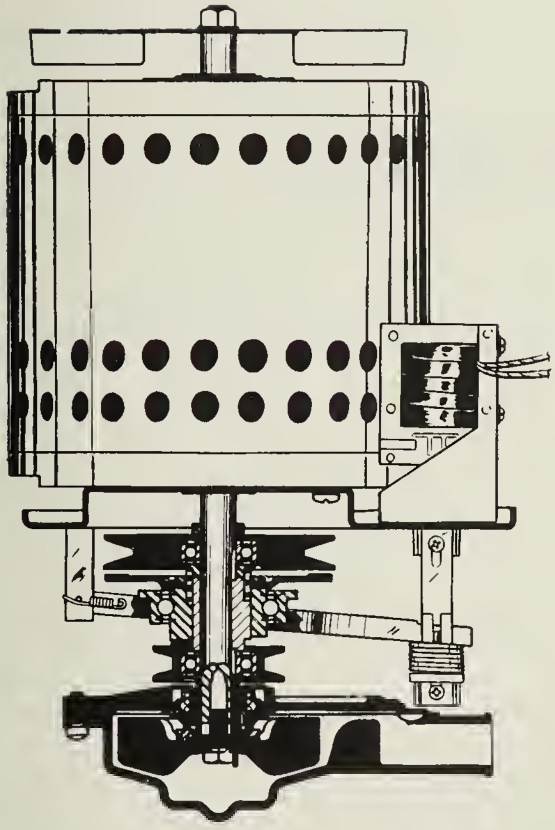


Figure 6-29. A motor, clutch, and pump assembly used in many of today's automatic washers.

this type of solenoid, the final one for discussion is shown in Fig. 6-29. This illustrates the motor-and-clutch-assembly mechanism used in many of today's clothes washers. Briefly stated, the two motor drive pulleys, the clutch assembly, the specially designed two-speed and reversible motor, and the solenoid make it possible to obtain dual speeds for both pulsating and spinning operations. The solenoid device, however, contributes to only one of these operations, the high-speed (850 r/min) spin. Like the other applications, the solenoid coil is energized with 120-V current through the timer contacts. When high-speed spin is desired, the coil is energized and attracts the movable core in an upward direction. This, in turn, actuates a connecting yoke which lifts the clutch assembly against the larger-diameter drive pulley. The clutching action causes the tub to increase in speed from 330 to 850 r/min. It should be remembered that high-speed spin cannot be obtained without first having a short period of slow speed. This is necessary to prevent overloading of the motor.

Like any electric device, solenoid coils may develop opens, shorts, or a path to ground. In some instances the windings become charred because of misapplication and/or high current flow through them. This usually results in a shorted coil. In any event, the valve fails to function and must be replaced. Each coil has a rated resistance in ohms and can be readily checked electrically for malfunction by an ohmmeter (see (p. 153).

The question now is, how can the core remain within the magnetic field on ac valves when the current is continually changing direction? This is possible because of the speed of current change and the residual magnetism of the core. In other words, on 60-Hz current the current changes direction 120 times each second, which is too rapid for the core to lose its magnetism between changes.

Electricity and heat

CHAPTER

7

In Chap. 1, it was stated that heat is a form of energy and that electric energy is closely associated with heat. It is not surprising, therefore, that someone discovered that electricity could be produced and caused to flow through a circuit by the application of heat. It was known before this discovery that the flow of electricity through a conductor caused the conductor to heat. For the sake of clarity, these two allied subjects will be covered separately.

ELECTRICITY BY HEAT

Alessandro Volta, during his experiments, with his primary cell, discovered that two different metals placed in contact with each other assume slightly different potentials. This is due to the fact that the metal with the fewer number of free electrons attracts some from the metal with the higher number.

The discovery of thermoelectricity, however, is accredited to a German physicist, Thomas J. Seebeck, who made this discovery in 1826. This is called the *Seebeck effect* and alludes to the effect by which an electromotive force is developed in a circuit consisting of dissimilar metals whose junction points are maintained at different temperatures.

Although the Seebeck effect is applicable to practically any two dissimilar metals, it has been found that some combinations of metals produce a stronger current flow than others at the same temperature difference. From a practical standpoint, the manufacturers of devices which function on the Seebeck effect select the kinds of metals according to the application of the device. Some popular devices have one conductor made either of iron or Nichrome and the other of constantan. Constantan is an alloy made of copper and nickel; usually it consists of 55 percent copper and 45 percent nickel.

Thermocouples

When dissimilar metals are joined for the purpose of establishing an electric circuit produced by heat, they form what is called a *thermocouple*. A basic thermocouple is illustrated in Fig. 7-1. Note that the two conductors are of iron and constantan. When heat is applied to one of the connections it is called the *hot junction*. The other connection is then called the *cold junction*.

As indicated by the arrows, the current always flows in one direction, like regular direct current. It also flows from the metal having the most free electrons to the one with the least; in this instance, the current flows from the constantan, across the hot junction, and to the iron. The metals used in quality thermocouples are not readily affected by oxidation and corrosion. These are especially desirable characteristics due to the purpose for which these devices are used.

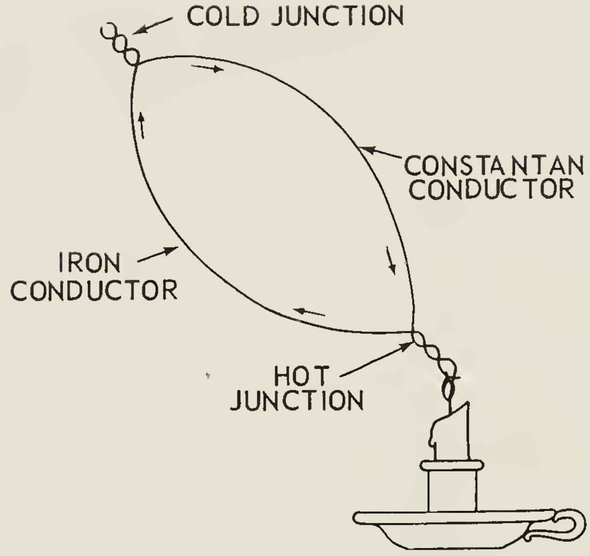


Figure 7-1. A basic thermocouple.

Before discussing the application of thermocouples, we should have an understanding of the amount of voltage and current that can be produced in them. So far in the course, we have been discussing voltages of $1\frac{1}{2}$ to 2 V produced by a primary cell, and voltages as high as 69,000 V produced in transmission transformers. In the production of electricity by heat, an emf of only a few thousandths of a volt is developed. The conductors, however, are usually of such a low resistance that a sufficiently high current can be developed to produce an electromagnet strong enough to hold an armature against the core. Its maximum strength is a relatively few thousandths of an ampere.

One of the first practical appliance uses of a thermocouple was in late 1930, when it was introduced on electric ranges. Oven-temperature testers were added to range-testing equipment to check oven thermostat performance. The instrument was designed to indicate temperatures as high as 650°F. Later, thermocouples became an integral part of safety devices for gas

furnaces. These devices were usually referred to as *pilotstats* or *safety pilot relays*. Their function was to shut off the gas supply to the burner in the event of pilot light failure, thus preventing unburned gas from entering the furnace.

In like manner, a thermocouple safety device was used on early gas dryers to accomplish the same purpose as that provided for furnaces. Gas dryer safety devices of this nature closely parallel those used for furnaces.

Figure 7-2 illustrates the construction of a representative type of thermocouple used on all pilot safety switches. It also illustrates, in schematic, a basic electromagnet which is used to actuate an electric contact arm.

The outer sheath of the thermocouple tip is made of iron, while the inner conductor, which is bonded to the tip, is made of constantan. This forms the hot junction. The iron sheath is brazed to a brass connector sleeve which is, in turn, brazed to a copper tube. Inside the tube is an asbestos-insulated copper wire which is welded to the constantan. The brazed joint of iron and brass combines with the bond between the copper wire and the constantan to form the cold junction. When the hot junction is heated, thermal current is conducted through the inner copper wire to the electromagnet and returns to the iron sheath through the copper tube.

Now let us apply the thermocouple to a basic pilotstat and observe its operation from the illustration in Fig. 7-3.[7] In the ON position we note that the pilot light is heating the tip of the thermocouple. A sufficient current is flowing through the solenoid coil to hold the armature against the electromagnet, which in turn holds the gas valve open. If for any reason the pilot light goes out, the thermocouple gradually cools. The consequent reduction in current flow soon causes the spring-backed armature to drop out and close the gas valve as illustrated in the OFF position.

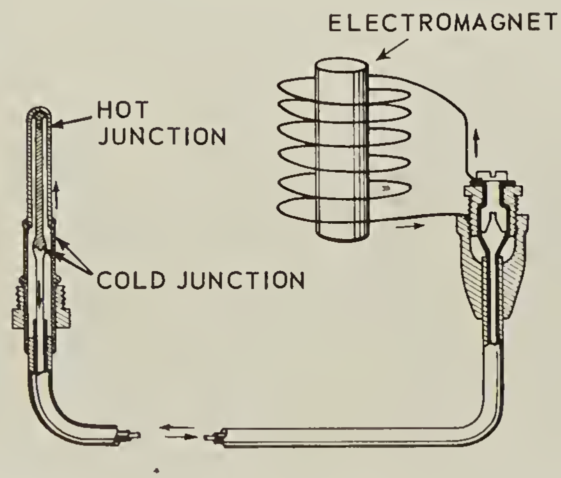


Figure 7-2. A pilotstat thermocouple and electromagnet.

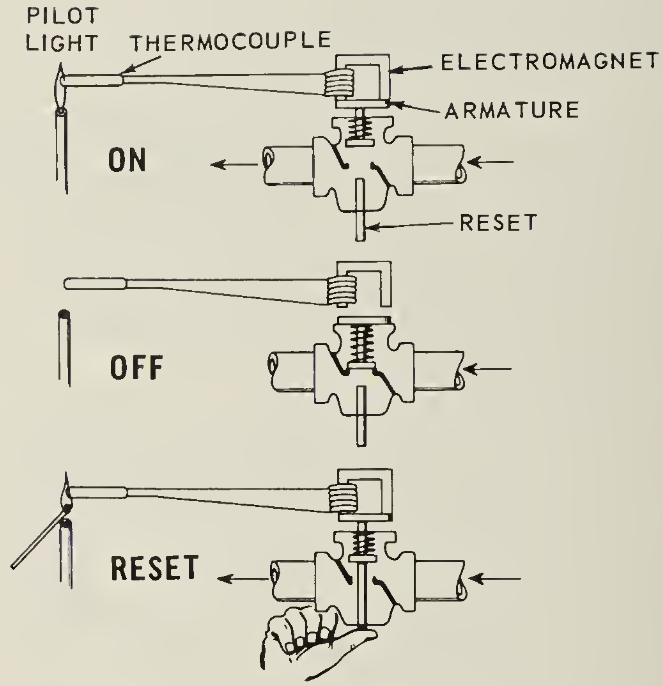


Figure 7-3. The basic operation of pilotstat.

The illustration at the bottom shows the method of resetting or starting the pilotstat. Although the thermal current through a thermocouple is sufficiently strong to hold an armature to the core, it is never strong enough to attract it. For this reason, after the pilot light is lit the armature must be held against the core until a strong current flow is established.

Figure 7-4 illustrates the internal arrangement of the components of a pilot safety relay currently used on some gas furnaces. This particular relay not only shuts off the main-line gas supply but also turns off the gas supply to the pilot burner in case of pilot light failure. In many instances, the pilot burner is connected to

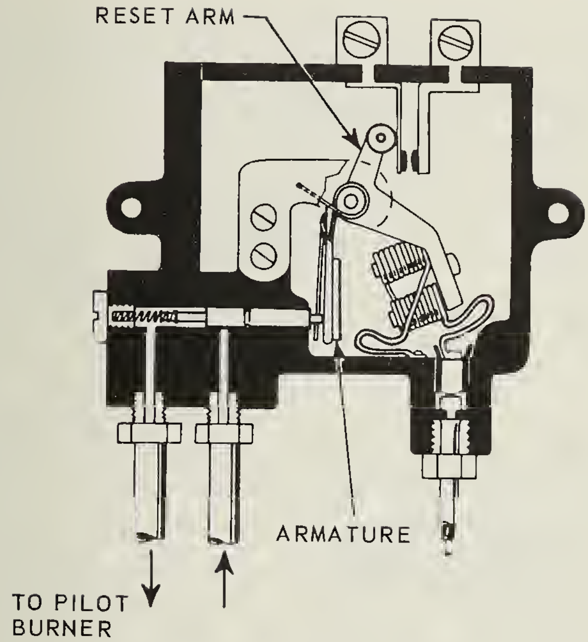


Figure 7-4. Typical internal arrangement of a pilot safety relay.

the gas line ahead of the solenoid gas valve.

In case the pilot light goes out, the small amount of unburned gas through the pilot burner is drawn up the chimney by the natural draft. The illustrated relay provides a wider margin of safety than other types. This relay has an external knob attached to the reset-arm shaft. When the knob is turned to the RESET position, a gas passage to the pilot burner is provided and the armature is held against the core. After the pilot burner is lit and thermal current flows through the relay coil, the knob can be released. This causes a spring to exert pressure against the contact-reset arm and close the circuit through the solenoid-valve coil, which permits the main burner to ignite.

The amount of voltage required to hold the armature to the core varies with the make and model of pilotstat. Generally speaking, the voltage through the thermocouple only should be between 28 and 42 mV and should not exceed 50 mV. When the thermocouple is connected to the solenoid coil, the voltage should be between 15 and 20 mV. If the voltage drops below 12 mV, the armature may drop out and shut off the gas supply to the burner. This could be caused by one of several conditions such as a carbonized hot junction due to poor fuel mixture, a deteriorated hot junction due to excessive heat, or an improperly adjusted or positioned pilot flame.

In order to check thermocouple and pilotstat operation, a millivoltmeter is required. A millivoltmeter and an oven-temperature tester work on the same principle of electromagnetism. They differ basically only in the calibrations on the dial. To illustrate the similarity between the two instruments, a hookup of both is shown in Fig. 7-5. A temperature-voltage table is given below.

Degrees F	Millivolts
212	5.3
392	10.8
752	21.8
1112	33.2
1472	45.5
1832	58.2

Let us assume that only the thermocouple is connected to the millivoltmeter and the hot junction is heated to approximately 400°F. The

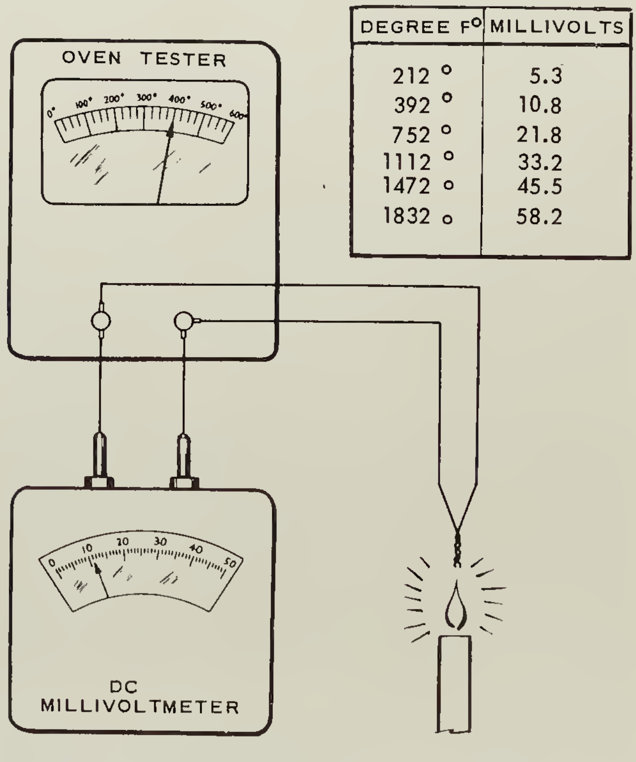


Figure 7-5. The temperature versus voltage.

voltage in the thermocouple only will be approximately 11 mV and will be so indicated on the millivoltmeter. Likewise, if the thermocouple only is connected to the oven tester, the indicator will show 400°F. When the instruments are connected together, however, the resistance of the coils inside the instruments will cause the readings of both to be somewhat less than the readings indicated when the instruments are separately connected to the thermocouple.

HEAT BY ELECTRICITY

Along with the discovery of dynamic electricity, or current, was the discovery that heat is produced whenever current flows through a conductor. Just as methods were devised to generate and control electricity, so were methods devised to control the amount of heat produced. Because of the heating effect of electricity, many modern heating appliances, such as toasters, coffee makers, electric blankets, irons, ranges, clothes dryers, etc., are made possible. Even our lighting systems produce illumination because of the heat of electricity. If it were not for the heating effects of electricity, it can truly be said that we would be living in the Dark Ages.

Standards

In spite of the innumerable benefits derived from the heat of electricity, there is one major undesirable characteristic which must be considered—the fire hazard. Every year millions of dollars' worth of property damage is caused by fire resulting from overheated conductors in improperly wired homes and business establishments. Much property and personal damage also has resulted from improperly designed or installed electrical equipment. To reduce the possibility of damage to property or injury to personnel, rules and regulations, called *codes*, have for many years been established on a national and local basis.

National electrical code The first rules for the installation of electrical wiring were established in 1881 by the New York Board of Fire Underwriters. By 1896 other underwriters groups had established additional rules. The National Fire Protection Association was founded at this time. In 1897, the first National Electrical Code was prepared by a joint committee of various fire underwriters' representtatives and persons from other interested organizations. The code is now revised every two or three years by the Electrical Committee of The National Fire Protection Association.

The purpose of the code is the practical safeguarding of persons, buildings, and their contents from hazards arising from the use of electricity for light, heat, and other purposes. But remember, the National Electrical Code (NEC) is a code of *minimum* standards. That is, any wiring or electric apparatus that does not meet its standards is rejected. Nevertheless, there is no reason why a city or state cannot adopt even stricter standards than the ones in the code.

Local electrical codes. Most cities in this country have established their own organization for the purpose of making certain that all electrical installations meet safety requirements. In all instances they subscribe to the national code and often establish additional regulations according to local conditions. Requiring electricians to be licensed also insures better and safer installations. The necessity of obtaining permits to install wiring and the inspection required after installation have contributed considerably to the reduction of fire and personal hazards. It is a good policy to be familiar with both national and local codes when installing commercial refrigerating equipment and household appliances.

Underwriters Laboratories Inc. The Underwriters Laboratories Inc. (UL) is a nonprofit organization which tests electrical devices to make certain that they are designed and constructed in accordance with the National Electrical Code.

The organization was founded in 1894 and is sponsored by the National Board of Fire Underwriters. Manufacturers of electrical appliances

Figure 7-6. Various forms of "UL" label indicate that the item is tested and meets specific underwriter standards.

or devices can submit their products to one of the UL testing stations for approval. Only the cost of making the test is charged to the manufacturer. If the device or equipment meets the requirements, a UL label is placed on it and a card so stating is sent to all inspection departments in the country that require such equipment to be approved. If the equipment does not meet UL requirements, the laboratory informs the manufacturer of the changes required.

Housing Wiring

The term *house wiring*, as used here, means all the built-in wiring and accessories for all types of buildings having 120-V and/or 240-V service.

There is no mystery to house wiring. When it is properly installed such things as lights, motors, heaters, and other electrical appliances can operate on the electricity (electric power) furnished by it. Today, electric power generally is furnished by a commercial power company (the source). The power company is responsible for making the electric power available (conducting it) to the purchaser. This is accomplished by means of main power lines, which serve many customers, and by individual service lines, which connect each customer with the main power lines.

A customer receives electric power from the end of the service line (usually, the company wires terminate at least 10 feet above the ground level on the outside of the building) and it is the customer's responsibility to be sure that it is safely conducted throughout the home to wherever needed. House wiring accomplishes this. Adequate house wiring will provide for all of the customer's present and future electric-power requirements. But, unfortunately, as a service technician you will find that many of your customers' homes are inadequately wired. This can be the cause of many of their appliance problems.

If the house is 15 or more years old, it probably has "outgrown" its wiring. When it was built, the wiring was probably sufficient for the basic electrical needs of the time. But, as more electrical devices have been developed and introduced, newer standards of electrical living have become commonplace. Table 7-1 lists typical major appliances and the current they consume.

The service technician can usually determine that the home is inadequately wired, without

Table 7-1. Load requirements.

Type of appliance	Typical watts	Usual* voltage	Size wires	Fuse size recommended, A
Electric range	12,000	120/240	3 No. 6	50–60
Dishwasher	1,200	120	2 No. 12	20
Garbage disposer	300	120	2 No. 12	20
Refrigerator	300	120	2 No. 12	20
Home freezer	350	120	2 No. 12	20
Automatic washer	700	120	2 No. 12	20
Automatic dryer	5,000	120/240	3 No. 10	30
Rotary ironer	1,650	120	2 No. 12	20
Power workshop	1,500	120	2 No. 12	20
Television	300	120	2 No. 12	20
20,000-Btu air conditioner	1,200	120	2 No. 12	20
Heating plant	600	120	2 No. 12	15–20

* Nominal voltages usually specified by manufacturers.

any meter checks, if any of the following conditions are observed:

1. Lights dim when appliances are turned on.
2. Toasters, heaters, and irons heat up too slowly.
3. Fuses blow or circuit breakers trip too often.
4. Television picture shrinks in size or becomes hazy when electrical appliances are turned on.
5. Motors overheat or slow down under normal work load.
6. Multiple connections are used to operate several appliances.
7. Long cords are strung around room to plug in lights.

It is good customer relations to inform clients that their home is inadequately wired. Besides not getting full efficiency from appliances, overloaded and overheated wires run up electricity bills and can cause fires. To help educate a customer, as well as yourself, here are some important points to keep in mind about house wiring.

The meter is supplied by the utility company. The company usually furnishes and installs all wiring leading to the meter. In some areas, the company provides the meter socket. Some utility companies require that the customer provide the meter socket. All wiring on the

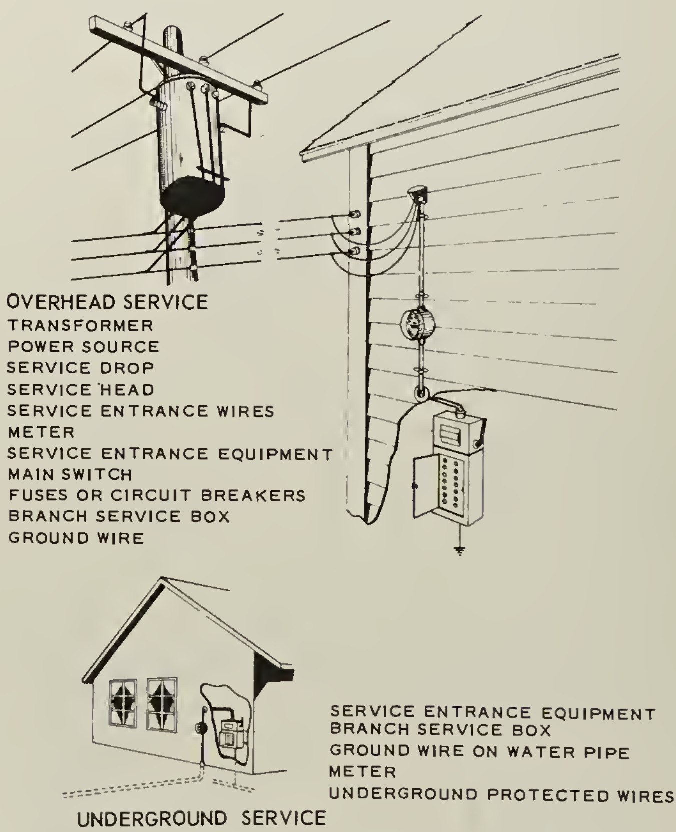


Figure 7-7. Service entrance equipment.

house side of the meter, as previously stated, is the homeowner's responsibility. Use of thin-wall conduit (p. 131), rigid conduit (p. 132) or service-entrance cable depends largely upon local regulations.

The incoming power lines are anchored to the building or yardpole by service insulators, which are installed as high off the ground as is practical. The National Electrical Code requires a clearance of at least 10 ft above sidewalks and 18 ft above driveways. The service head must be attached to the building above the topmost insulator, as shown here, to prevent rain from entering the system. If the building is low, a steel service mast or a 4 × 4-in wooden mast may be used to elevate the service wires. The conduit or entrance cable should be properly and securely fastened to the house, and the wires should be brought into the house through an entrance ell. In some areas, the service wires are brought into the house underground.

Once inside the house, the wires are connected to the entrance service. Here is where the main disconnect switch and branch-circuit fuses or circuit breakers are placed. Some local codes require that main disconnect switches be outdoors. From this junction point, branch circuits transmit the current to various rooms in the house.

Service-entrance switches. The service-entrance switch not only provides overload protection for branch circuits, but it is also a means for disconnecting all current from power lines when making changes or repairs on the wiring system.

Two types of service-entrance switches are in general use. The most common and least expensive is the fuse type (see p. 101). The other is the fuseless or circuit-breaker type (see p. 103). The latter is to be preferred, since breakers are simply reset when overloads occur—they need not be replaced. Each type is rated in amperes and must be of sufficient capacity to accommodate the maximum amount of current which which will be used *at one time.* When selecting the entrance switch, consider both your present and future electrical needs. It is wise to recommend to a customer a switch of 100-A (24,000 W) capacity as the minimum for average residential use. Larger homes, or those with more than average electrical demands, should have entrance switches of up to 200-A capacity.

Modern combination fuse-type entrance

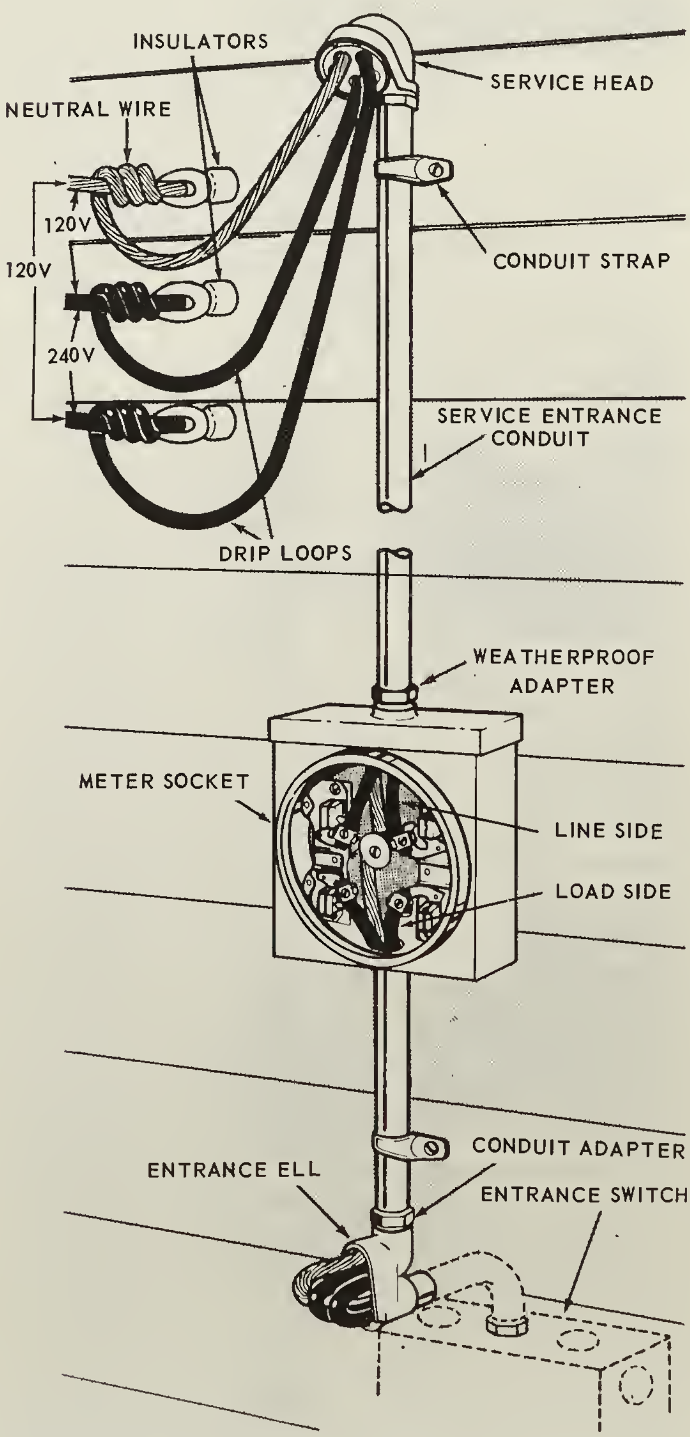


Figure 7-8. Service entrance using conduit.

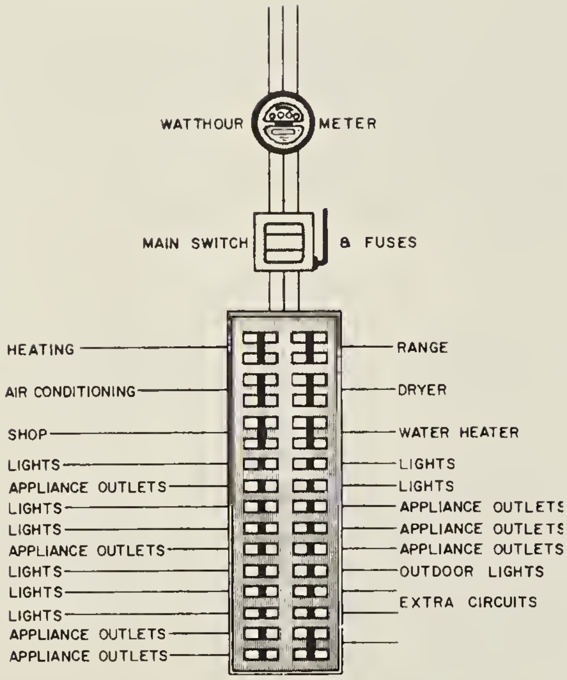


Figure 7-9. The branch circuit distribution panel.

switches eliminate the need for separate safety switches for individual 240-V appliances. Two cartridge-type fuses for protecting the range, water heater, or dryer are mounted on a removable block which can be easily pulled from the entrance switch; fuses can be removed while the block is in your hand—the circuit remains dead. Plug-type fuses protect 120-V circuits. These fuses are available in standard tamperproof time-delay and circuit-minder types. In addition to pullout blocks for 240-V appliances, some types of entrance equipment have a main pullout switch for shutting off all current entering through the service-entrance switch. This main disconnect is fused to the total amperage capacity of the box. As a rule, the main disconnect and the branch-circuit fuses share the same cabinet. In some cases, however, local codes or building needs may require a separate main-disconnect-switch installation.

Circuit-breaker entrance switches have a marked advantage over fused equipment. Fuse blowouts caused by temporary overloads are eliminated. When a circuit is overloaded or a short occurs, the breaker will trip automatically, stopping the flow of electricity through the circuit. To restore service, find and correct the fault and flick the handle to ON position. Circuit breakers take temporary overloads such as the starting of a washing machine, refrigerator, etc., without tripping. To disconnect all power, flick the handles on all circuits to OFF position unless a separate disconnect switch is installed between the power lines and the entrance switch. Circuit breakers commonly used include the double-pole breaker, the single-pole breaker, and the twin single-pole breaker. Each 240-V circuit requires a double-pole breaker. No current-carrying parts are exposed in circuit-breaker assemblies.

When a fuse blows or a circuit breaker trips, it is well to remind a customer that this is a danger signal which calls for investigation of the cause. Something connected to a circuit may be defective, or perhaps too many devices are in use on the circuit at one time. If a fuse blows when a motor device is turned on (motors draw much more current when starting), a time-delay fuse (see p. 102) may solve the problem.

A two-wire service is usually a 120-V line. A three-wire service is a 120/240-V line. Two of these wires (the hot wires) carry the 240-V current. If the third (neutral) wire is paired with either one of the other wires, a 120-V current is obtained. (*Note*: So-called 120-V circuits may actually vary between 105 and 135 V; 240 V may be 200 to 260 V—see p. 75.)

The size of the wires behind each of the fuses or circuit breakers will tell the wattage they can handle. You should have for each

No. 14 wire	a 15-A fuse, 1,750-W capacity
No. 12 wire	a 20-A fuse, 2,300-W capacity
No. 10 wire	a 30-A fuse, 2,600-W capacity

Interior wiring. Basically, there are three types of approved interior wiring in general use for modern residential and farm applications. They are (1) Flexible armored cable, usually called "BX," a trade name; (2) Nonmetallic cable or "Romex," also a trade name and plastic-covered cable; (3) Thin-wall conduit, also called "EMT." Under certain conditions, the

code calls for the use of either rigid conduit or flexible electric conduit, called "Greenfield."

Flexible armored cable (*BX*) consists of two or three insulated wires, individually wrapped in spiral layers of tough paper, which are protected by a galvanized steel casing. It is particularly recommended for indoor use in dry areas for either old or new work, especially where a good ground arrangement, such as connection with city water-system piping, is available. *Caution*: BX is not designed for use outdoors or underground. It is easy to install and acceptable in most localities. It affords a continuous ground and provides good mechanical protection to the wires. Use it indoors, for both exposed and concealed work—along walls, ceilings, etc., or in hollow spaces of walls, floors, and ceilings. This cable may also be imbedded in plaster or other masonry, except in damp locations. Because it is versatile and easy to use, it is frequently selected for the extension of conduit systems or for remodeling work.

Non-metallic sheathed cable, or *NM cable* (generally called "Romex"), is covered with a thermoplastic jacket. Inside are two or three insulated wires, each of which is covered with thermoplastic insulation and spirally wrapped with paper tape. This cable has a long life and is resistant to fire, moisture, and acidic vapors. It is recommended for indoor use in homes, garages, barns, and all outbuildings for both old and new work. *Important*: Do not use outdoors, underground, or in masonry. Use it inside, for both exposed and concealed work.

Plastic-covered cable, a comparatively new type of cable, is unusually tough and versatile. It is similar to type NM cable, except that it has heavier insulation. A rot- and fire-resistant plastic covering gives it high resistance to acids, moisture, and mechanical damage. It is especially suitable for use in damp locations, such as barns, milk houses, well pits, etc. This cable can be installed in brick or masonry walls and is ideal for use indoors and out, in wet or corrosive locations, or underground between buildings.

Thin-wall conduit (*EMT*) is almost universally accepted for general wiring, especially for new work. It affords greater protection to wires than other types and permits grounding of the entire system. In many cities, thin-wall conduit is the required method of wiring a new building.

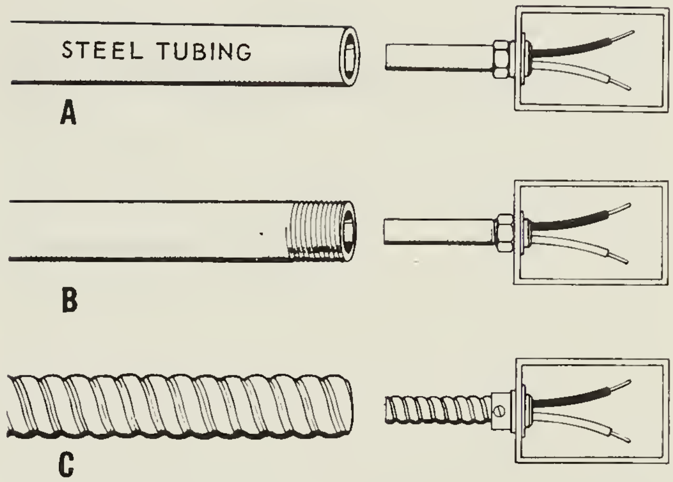


Figure 7-10. Three types of conduit: (A) Thin-wall conduit; (B) rigid conduit; and (C) flexible armored or BX conduit.

Thin or flexible conduit is easier to cut and bend than heavier rigid conduit. Connections are made with special threadless fittings. One of the advantages of thin-wall conduit is that insulated wires are drawn through after the conduit is installed. Likewise, future wiring changes are possible without removing the conduit. Use thin-wall conduit for both concealed and exposed work, indoors and out, and in wet or dry locations. However, it should never be buried in cinders or cinder concrete. Wires for thin-wall conduit are single-strand, unjacketed, and covered with color-coded thermoplastic insulation. This color-coded wire is available in white, black, and red. When ordering wire, be sure to order the correct number of feet by both color and size. Table 7-2 lists various gauges of wire and indicates the number of wires which several diameters of conduit can accommodate, as well as amperages which apply.

Wire sizes. Although it would seem that the subject of wires would be a relatively simple one, it actually involves many factors. This is

Table 7-2. Conduit size and ampere capacity of wires in conduit with number of wires (1 to 9) to be installed in conduit (exact number will vary according to local code).

Wire size	Ampere capacity	$\frac{1}{2}$-inch conduit	$\frac{3}{4}$-inch conduit	1-inch conduit	$1\frac{1}{4}$-inch conduit
14	15	4	6	9	9
12	20	3	5	8	9
10	25	1	4	7	9
8	35	1	3	4	7
6	45	1	1	3	4
4	60	1	1	1	3
2	95	1	1	1	3

partly due to the wide variety of kinds and sizes of wire, the different kinds of insulation used to cover wires, and the manner in which wires are identified (see Appendix B). In this book, we are not concerned with an in-depth study of wiring; but from a practical standpoint, we believe that service technicians should have an understanding of the current-carrying capacity of electrical wires and the proper protection which should be provided to protect wires against overheating.

The three major factors that affect the current-carrying capacity of a conductor are the amperage, the wire size, and the wire temperature. The higher the amperage, the smaller the wire, and the higher the wire temperature, the lower will be the wire's safe current-carrying capacity. In other words, if the wiring is to be maintained at a safe temperature, it must be large enough to carry *more* than the rated amperage of the connected load. Also, if the wiring is exposed to relatively high temperatures, its size should be increased accordingly.

Wires for electric circuits are identified by number. The larger the number, the smaller will be the diameter of the wire. The wires used for wiring homes and average-size business establishments range in numbers from No. 000 to No. 18. Wires larger than No. 000 are especially for industrial applications, where exceptionally high voltages and current are required. Wires smaller than No. 14 are used for many applications such as low-voltage control circuits, doorbells, solenoid coils, etc.

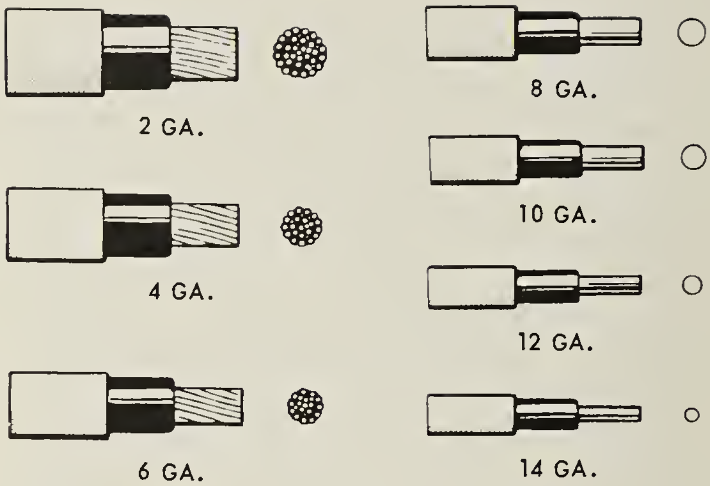


Figure 7-11. Actual size of copper conductors.

Table 7-3 lists the wires from size No. 000 to size No. 14 and their maximum current-carrying capacity in amperes. It should be noted that some of the ratings depend on the type of wire insulation. Local codes determine which type is acceptable for a particular locality. In most instances, types RH and RHW are acceptable for indoor wiring. The wiring sizes mentioned in the following discussion pertain to RH and RHW types.

Table 7-3. Wiring-size data (enclosed wires).

	Maximum ampere rating	
Wire size	Types R, RW, RU, T, and TW	Types RH and RHW
14	15	15
12	20	20
10	30	30
8	40	45
6	55	65
4	70	85
3	80	100
2	95	115
1	110	130
0	125	150
00	145	175
000	165	200

R = Code rubber
RW = Moisture-resistant rubber
RU = Latex rubber
T = Thermoplastic
TW = Moisture-resistant thermoplastic
RH = Heat-resistant rubber
RHW = Moisture- and heat-resistant rubber

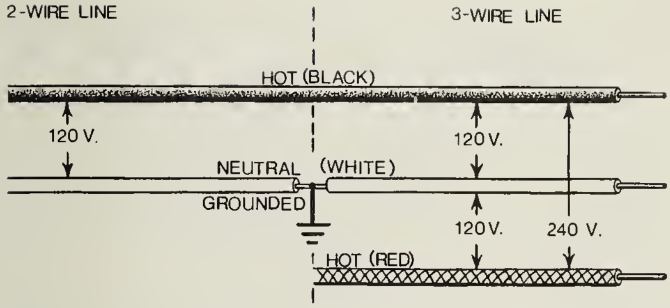


Figure 7-12. Diagram of two- and three-wire cables.

In house wiring, keep in mind that one current-carrying "hot" wire and one neutral wire must run to every 120-V current-consuming device. With two-wire cable, the black wire is hot; in three-wire cable the black wire and the red wire are hot, and the neutral wire is always white. To trace current flow, consider wires running from the previous outlet as the source and imagine that electricity flows over the hot wires, through the current-consuming device and back to the source over the neutral wire. Neutral wires should always run to current-consuming devices without interruption by a switch or fuse; only hot wires are attached to switches. If you should ever have to connect wires, remember to join black wires to black or red wires—never to white, except at switch loops in cable installations, where white wire should be painted black at both ends. At outlets, connect hot wires to dark (brass-colored) termi-

Table 7-4. Required conductor insulation for current-carrying circuits under 6,000 V.

Trade name	Type letter	Insulation	Outer covering	Use
Code	R	Code-grade rubber	Moisture-resistant, flame-retardant fibrous covering	General use
Moisture-resistant	RW	Moisture-resistant rubber	Moisture-resistant, flame-retardant fibrous covering	General use, especially in wet locations
Heat-resistant	RH	Heat-resistant rubber	Moisture-resistant, flame-retardant fibrous covering	General use
Latex rubber	RU	90-percent unmilled grainless rubber	Moisture-resistant, flame-retardant fibrous covering	General use
Thermoplastic	T and TW	Flame-retardant thermoplastic compound	None	T—general use TW—in wet locations
Thermoplastic and asbestos	TA	Thermoplastic and asbestos	Flame-retardant cotton braid	Switchboard wiring only
Asbestos and varnished cambric	AVA	Impregnated asbestos and varnished cambric	Asbestos braid	Dry location only
Asbestos and varnished cambric	AVB	Same as type AVA	Flame-retardant cotton braid	Dry location only
Asbestos and varnished cambric	AVL	Same as type AVA	Asbestos braid and lead sheath	Wet locations
Slow-burning	SB	3 braids of impregnated fire-retardant cotton thread	Outer cover finished smooth and hard	Dry locations only
Slow-burning weatherproof	SBW	2 layers impregnated cotton thread	Outer fire-retardant coating	Open wiring only

nals and white wires to light (silver-colored) terminals.

Types of house-wire insulation. Different types of insulation are given in the table here. The letter designation of the Underwriters Laboratories is given in the table for each wire, together with the trade name by which it is commonly known. The letter represents an abbreviation of the material used for insulation. For example, "R" indicates rubber insulation. This is the kind of insulation used for interior wiring. It is known also as *Code-Grade Type R* because it meets the requirements of the National Board of Fire Underwriters. (See Table 7-4.)

Branch circuits. A branch circuit is defined by the National Electrical Code as the part of a wiring system beyond the final fuse box protecting the circuit. Branch circuits carry electric current to appliance outlets, light fixtures, and switches.

The code recognizes four branch circuits with ratings of 15, 20, 30, and 50 A. The 50-A branch circuit is recommended for range and water heaters only. The 30-A branch circuit is usually used for appliances or lights in non-residential applications. The 20-A branch circuit (as well as the 30- and 50-A branches) can have only heavy-duty lampholders of the mogul or porcelain keyless type when used for lighting purposes. Also, the fixture wire to the lampholder must be no smaller than No. 14. The only branch circuit suitable for general lighting is the 15-A branch circuit. Any type lampholder may be used on the 15-A branch circuit, and this type of circuit may be used for appliances as well as for lighting. Table 7-5 lists the wire gauges for feeder and branch circuits.

The branch-circuit requirements for homes vary with local codes, but most are similar to those of the National Electrical Code. Under modern electrical practices, branch circuits are divided into the following three general classes, according to their use.

General-purpose circuits serve not only lights in all parts of the house, but also convenience outlets, except for those in the kitchen, laundry, and dining areas. These circuits usually require

Table 7-5. Wire gauges for feeder and branch circuits* (six or fewer conductors per raceway or cable).

	Continuous operation*		Noncontinuous operation*	
Amperes	Wire size—copper	Wire size—aluminum	Wire size—copper	Wire size—aluminum
15	14	12	14	12
20	12	10	12	10
25/30	10	8	10	8
35/40	8	6	8	6
45/50	6	4	6	4
60	4	4	4	4
70	4	3	4	3
80	3	2	3	3
90	2	1	3	2
100	1	0	2	1
110	0	00	1	0
125	0	000	1	00
150	00	0000	0	000
175	000	....	00	0000
200	0000	....	000	....
225	....	....	0000	....

* American Wire Gauge (AWG) sizes. Continuous loads are those expected to continue for 3 or more hours; noncontinuous loads are those where 67% or less of the load is expected to be continuous.

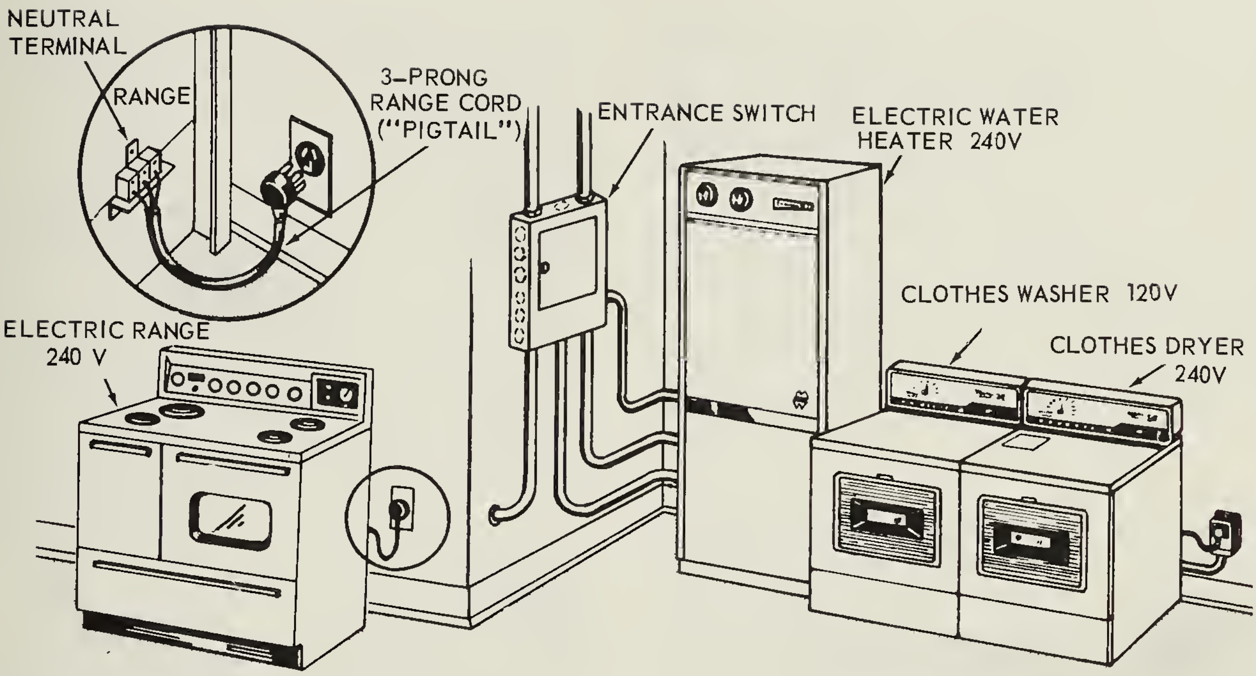


Figure 7-13. Wiring for typical 240-V appliances.

No. 14 wire, which cannot be fused at more than 15 A, to handle up to a maximum capacity of 1,750 W. For today's systems, we recommend the No. 12 wire as the minimum size, fused at 20 A to handle up to 2,300 W. Plan one of these circuits for each 500 ft^2 of floor area. Divide outlets evenly among circuits on different floors to avoid complete darkness if a fuse blows.

Appliance circuits are circuits with outlets for appliances alone. Install convenience outlets, independent of lighting fixtures, in the kitchen, laundry, and dining areas to serve the refrigerator, the washing machine, and portable high-wattage appliances. Plan at least one circuit of this type, using No. 12 wire. If more than one heavy-duty appliance will be connected to the same circuit, the use of No. 10 wire is recommended. It is often most practical to install three appliance circuits—two for kitchen appliances and one for the laundry room or basement.

Individual circuits are provided for major appliances. Wire size and types of fuses or circuit breakers needed for individual circuits serving one piece of major electrical equipment, such as a clothes dryer, range, water heater, electric space heater, air conditioner, etc., will depend upon the amperage rating of these appliances. *Major Appliance Servicing* and *Refrigeration, Air Conditioning, Range and Oven Servicing* give details on wiring these into a home's electric system.

Grounding the Wiring System

If an electric system is to be considered truly safe, close attention must be given to grounding details. The neutral wire of every electric system is required to be grounded at some point; that is, it must be in contact with the earth either directly or indirectly through another good electric conductor. Electrical equipment used where damp floors may be encountered should also be grounded. Grounding reduces the effect of accidental contact of the wiring system with high voltage or lightning. The National Electrical Code rules covering grounding are strict and *must* be complied with.

In areas having underground piped water service, the water pipe leading into a building provides the easiest and safest possible means of grounding the electric system (since the underground pipe makes excellent contact with the earth). A ground connection, from the entrance

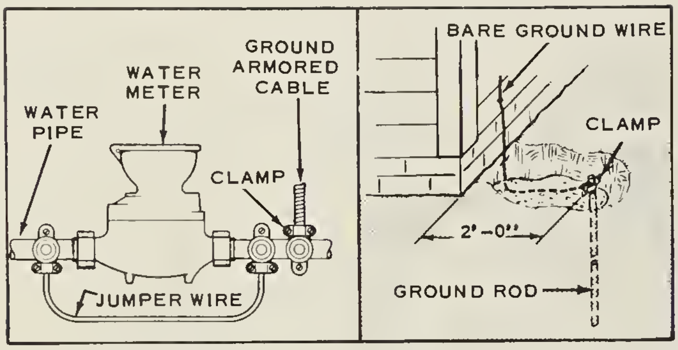


Figure 7-14. Methods of grounding city and rural electrical systems.

panel to the water pipe, can be made as indicated. The code requires that an additional jumper wire (bypass) be provided around the water meter, unless the ground wire can be connected to the pipe on the street side (outside) of the meter.

In areas not serviced by water-company pipes, a *grounding rod* must be used. This rod generally must be 8 ft long and must be buried 1 ft deep (to the top of the rod driven vertically down—check local codes). Also, it must be at least 2 ft from the building. It must be connected to the neutral wire of the service lines where the drip loop enters the entrance head.

Appliance Grounding

The one electrical problem most often overlooked (which bears directly on the safety of customer and service technician) is improper or inadequate grounding or none at all. It has been estimated by the Injury Control Program of the National Center for Urban and Industrial Health that there are 500,000 household injuries each year as the direct result of accidents with major and portable electrical appliances used in the home. The U.S. Bureau of Vital Statistics lists over 1,000 deaths each year due to electric shock. Proper grounding would have eliminated many of these injuries and deaths.

It has been determined that electric current (amperage), not voltage, is the dangerous ingredient of electricity. Measurements of a 60-Hz, 120-V current and the predicted body reaction are given in Table 7-6.

A person's skin, when dry, may have from

Table 7-6. Effect of current on the human body.

Current	Effect
0.05 to 2 mA (5/10,000 to 2/1,000 A)	Just noticeable
2 to 10 mA (2/1,000 to 10/1,000 A)	Slight to strong muscular reaction
5 to 25 mA (5/1,000 to 25/1,000 A)	Strong shock, inability to let go
25 to 50 mA (25/1,000 to 50/1,000 A)	Violent muscular contraction
50 to 200 mA (50/1,000 to 200/1,000 A)	Irregular twitching of the heart muscles with no pumping action (ventricular fibrillation)
100 mA and over (100/1,000 A)	Paralysis of breathing

100,000 to as high as 600,000 Ω resistance; however, when the skin is wet (such as when perspiring), resistance can drop below 1000 Ω. Let us assume a technician is working on a 120-V motor with an insulation break leaking current to an ungrounded motor frame. Ohm's law (volts/ohms = amperes) may be used to compute the amount of current received by the technician's body. If his skin is dry, the current would be 120 V/100,000 Ω = 0.0012 A, or 1.2 mA. This current would be barely noticeable. However, if the technician is perspiring, his skin resistance may be 1,000 Ω or less (with a break in the skin it can be as low as 200 Ω). Using Ohm's law, the current would be 0.12 A, or 120 mA (120 V/1,000 Ω = 0.12 A). This is more than a lethal current. If the motor frame had been grounded, this leaking current would have bled to the ground, and the fuse or breaker would generally have "blown." Remember, as little as 0.025 A at 120 V can kill.

There are meters available for measuring current leakage, but a technician can make his own with the following components:

Four $\frac{1}{2}$-A, 600-V diodes
One 7.5-W lamp (7C7 bulb)
One 1500-Ω variable resistor
One 0.15-F, 400-V capacitor
One service-cord adapter plug
One dc milliampere meter

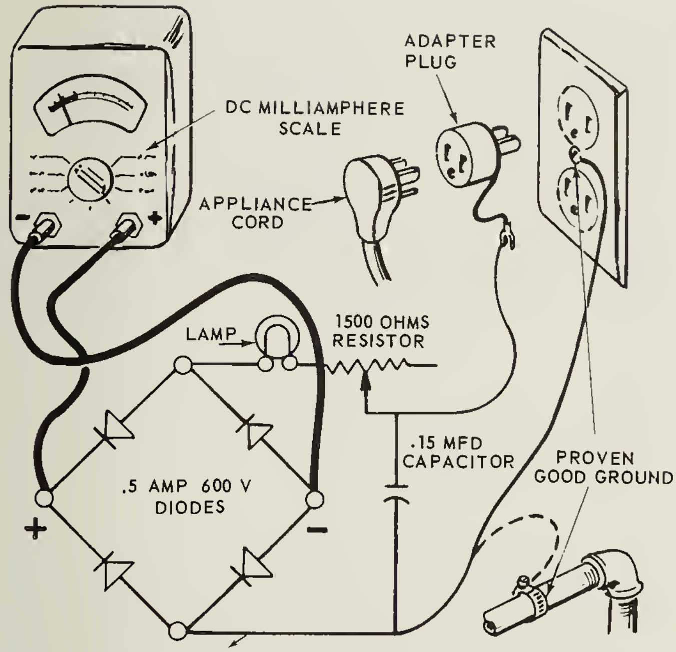


Figure 7-15. A simple way of measuring current leakage.

Assemble the components according to the diagram in Fig. 7-15, being mindful of the polarity of the diodes. A small piece of printed circuit board can be used for mounting the parts.

To read leakage, attach one lead to the adapter ground wire and the other to a known good ground. Plug in the appliance through the adapter plug. All leakage to ground must now go through your testing circuit. If the lamp lights, there is a high-current short. Do not test with your milliampere meter until the short has been repaired. If the lamp does not light, you may attach your meter and read the leakage through all the cycles of operation.

A leakage of more than 0.5 mA (0.0005 A) is an indication of excessive leakage. In all probability, it is caused by a breakdown or deterioration of the insulation on a component. You can determine which component is leaking current by isolating the part which was energized at the time the leakage occurred. There will always be some leakage from an inductive load (0.2 mA or less), but when it is more than 0.5 mA, a noticeable shock can be felt.

If you received a shock from an appliance any time you touched it and ground, would interchanging the neutral and hot line to the appliance cure the problem? The answer is *no.* Interchanging the neutral and hot line only puts the appliance OFF-ON switch in series with the hot line; power is not applied to the appliance until it is turned on. The fault causing the shock is still there but is evident only when the offending component or cycle is energized.

A good rule of service is to check each appliance for current leakage to ground when a service call is made. In general, all major appliances today are grounded—some properly, some improperly. By isolating the appliance ground at the wall receptacle with an adapter plug, and then reading the current from the green wire of the adapter plug to a known good ground, it can be determined if there is a higher-than-normal current leakage to the cabinet or frame of the appliance. If a high current is present, caution should be taken in working on the appliance while the power cord is plugged in. This current could be the source of the trouble that made the service call necessary.

An electrical ground is required on every appliance regardless of age. Older appliances with two-prong service plugs should be grounded with a separate 14-gauge ground wire as shown in Fig. 7-16. It is attached between a convenient screw on the cabinet of the appliance and a

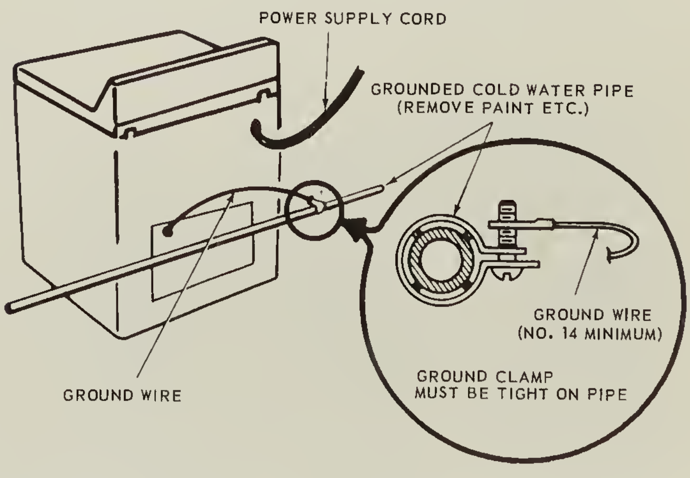


Figure 7-16. Proper grounding of a washer having a two-prong plug.

cold-water pipe or some other locally approved ground, such as a ground rod. *Never* ground to a gas supply line. Make certain that there is a good electric contact at the cabinet and ground connection. When grounding to a cold-water pipe, the pipe must have metal continuity to electrical ground and not be interrupted by plastic, rubber, or other electrically insulating connectors (including water meter or pump). Should such insulating devices be encountered, a jumper wire must be connected across them. Do not connect the machine to the electric supply until it is permanently grounded. *Caution:* Whenever the ground wire is disconnected for any reason, always make sure it is replaced before plugging in the supply cord.

Effective with the 1970 models, all major household appliances were required by Underwriters Laboratories to be grounded. Therefore, all units produced since then are supplied with a three-wire grounded service cord and mechanical grounds to all electric components and to cabinets, liners, and doors (where required).

When installing a grounded appliance in a home that does not have a three-wire grounded receptacle, under no conditions is the grounding prong to be cut off or removed. It is the personal responsibility of the customer to contact a qualified electrician and have a properly grounded three-prong wall receptacle installed in accordance with the appropriate electrical code.

The following procedure will provide a method for determining a properly grounded and polarized wall outlet or adapter plug. Checking the wall outlet or adapter plug prior to plugging the appliance line cord into the wall outlet or adapter plug is necessary, to provide the consumer the fullest protection from an electric shock. For example, if an appliance using a three-wire line cord is plugged into an ungrounded wall outlet or adapter plug, and an electric component should short-circuit, an electric circuit is provided to the outside of the cabinet by the internal ground wires (green or green with yellow stripe wires), and the cabinet becomes "hot" or "live" with electricity. If the consumer should touch the cabinet while touching a grounded surface (counter trim, water faucet, etc.), the consumer would receive an electric shock. Under certain conditions, an electric shock could be deadly. However, if the wall outlet or adapter plug is grounded, the cabinet will not become "hot" or "live," since there is an electric circuit through the ground wire back through the line cord and wall outlet. Again, to assume that the consumer is being protected by the three-wire line cord, we must determine that the wall outlet is properly wired prior to plugging in the appliance line cord. *Note:* If the following checks indicate that the wall outlet is not properly wired, advise the consumer to contact an electrician.

To test a three-terminal wall outlet (Fig. 7-20), use a voltmeter to check for proper voltage, correct polarity, and ground as follows:

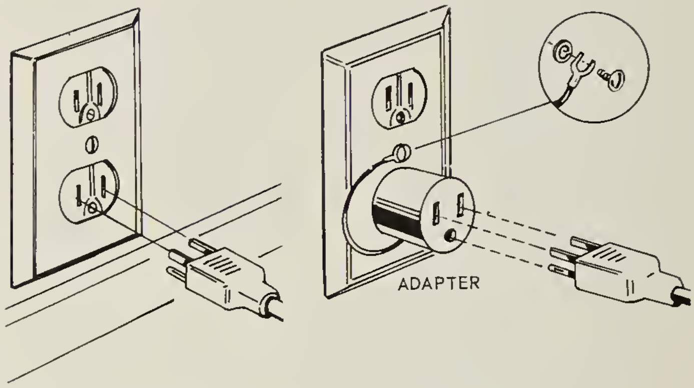


Figure 7-18. A properly grounded plug and the use of a temporary adapter.

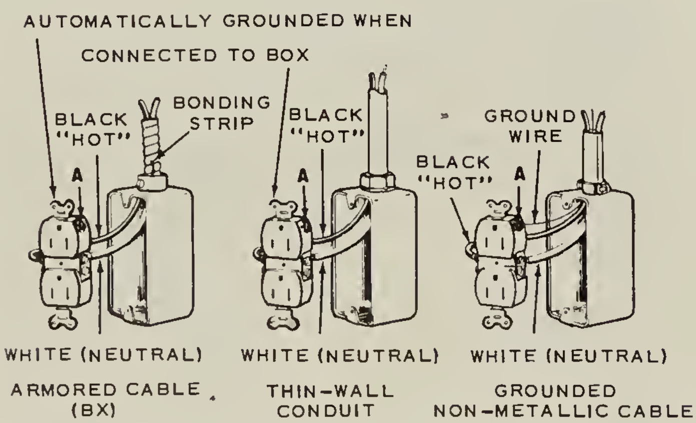


Figure 7-17. The grounding of outlet boxes.

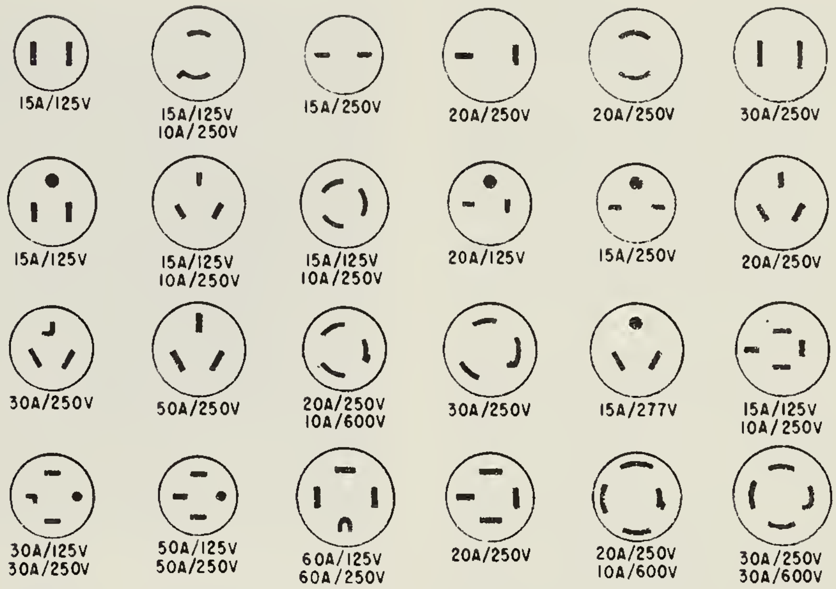


Figure 7-19. Standard attachment plug and connector configurations.

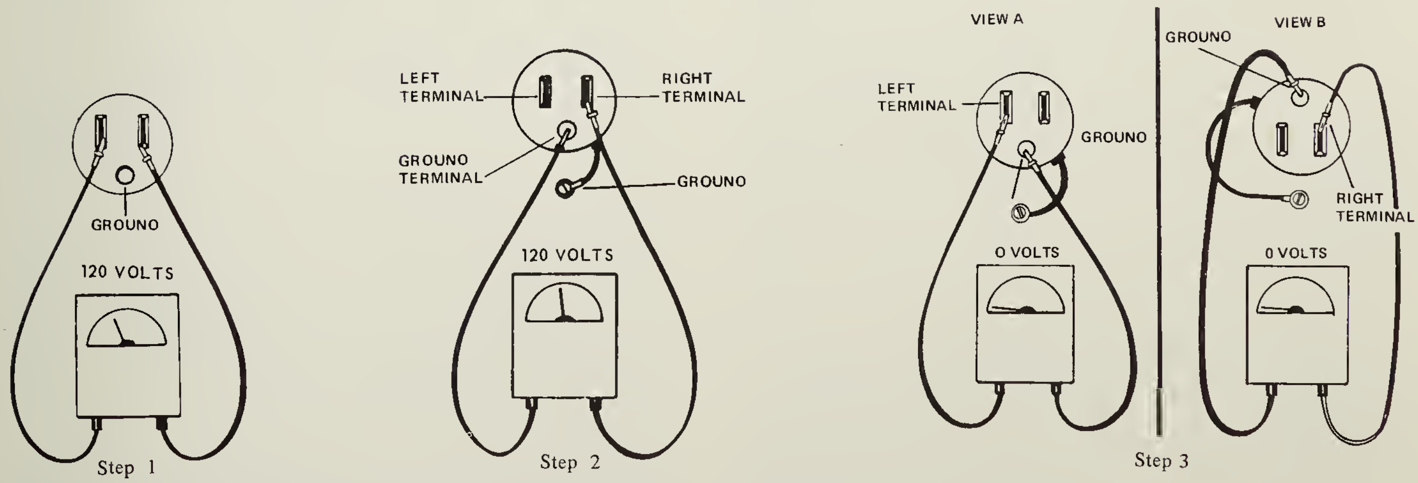


Figure 7-20. Checking a three-terminal wall outlet for voltage, polarity, and ground.

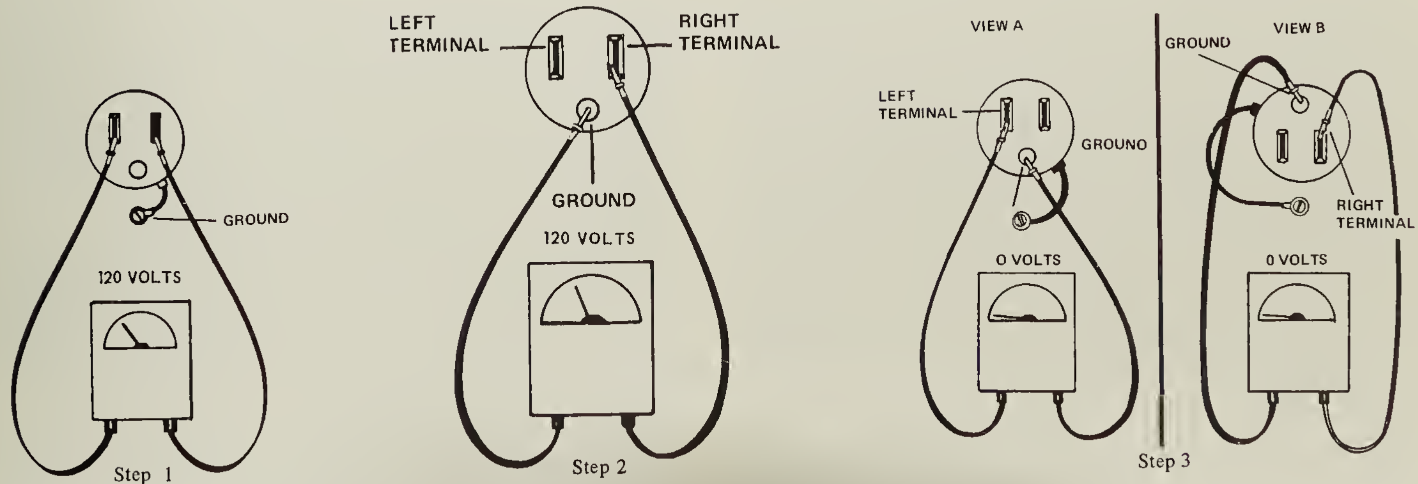


Figure 7-21. Checking a two-terminal wall outlet for voltage, polarity, and ground.

1. Check for voltage with a voltmeter, as shown here.
2. Check for ground with a voltmeter, as shown here. If the voltmeter does not indicate voltage, move the meter probe from the right terminal to the left terminal. If the voltmeter still does not indicate voltage, then you can conclude that the ground lead is not grounded properly.
3. Check for proper polarity with a voltmeter, as shown here. *Note:* The position of the ground terminal on the wall outlet determines the position of the voltmeter test probes for this check. See views A and B. If the voltmeter indicates 0 V, plug the refrigerator into the wall outlet. If the voltmeter indicates 120 V, the polarity is reversed at the wall outlet. To correct, install an adapter plug and repeat the checks outlined in the next series of tests.

To test a two-terminal wall outlet with an adapter plug installed, use a voltmeter to check for proper voltage, correct polarity, and ground as follows:

1. Check for voltage at adapter with a voltmeter, as shown in Fig. 7-21.
2. Check for proper ground with a voltmeter, as shown here. If the voltmeter does not indicate voltage, move the test probe to the left terminal. If there is still no indication of voltage, a ground wire must be added from the wall outlet to the fuse box. Advise the customer to contact an electrician.
3. Check for proper polarity with a voltmeter, as shown. *Note:* The position of the ground terminal on the adapter plug determines the position of the voltmeter test probes for this check. See views A and B. If the voltmeter indicates 120 V, then the polarity is reversed. To correct, unplug the adapter plug and rotate the adapter plug 180°; plug the adapter plug back into the wall outlet and plug in the appliance line cord to the adapter.

In addition to the methods just outlined for checking a wall outlet or adapter plug, there are several testing devices on the market which will check a wall outlet properly. Figure 7-22A shows a typical receptacle tester, which plugs into the wall outlet. This tester uses three lights with certain combinations of lights indicating whether or not the wall outlet is properly wired. A receptacle can also be checked with a voltmeter (Fig. 7-22B), or a neon test lamp (Fig. 7-22C).

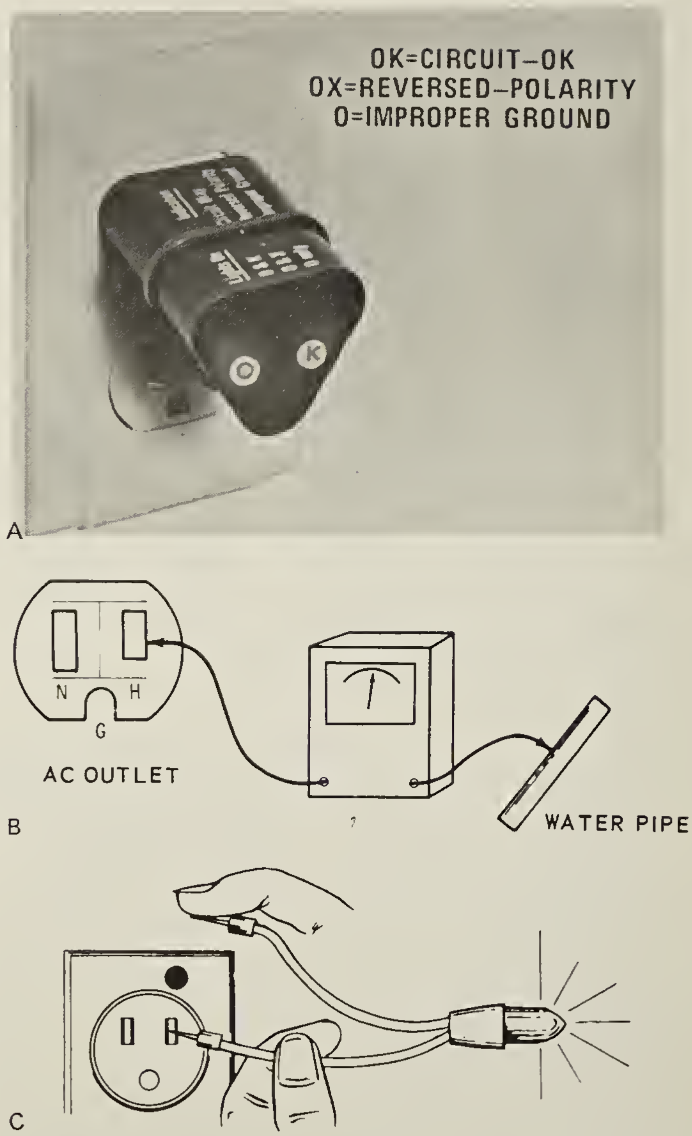


Figure 7-22. (A) Ground monitor in use. (B) Checking a receptacle for leakage with a voltmeter. (C) Checking the polarity with a neon test checker.

It is important to keep these points in mind when servicing an appliance:

1. When removing an electric component from an appliance, disconnect the ground wire last.

2. When installing an electric component to an appliance, connect the ground wire first.
3. It is extremely important that the service technician replace any and all grounds (green or green with yellow stripe wires) prior to completion of the service call. Under no conditions should a ground wire be left off; to do so will cause a potential hazard to the service technician and to the customer.

HEATING ELEMENTS

Our discussion of overload protectors, in Chap. 6, dealt with the ill effects of the heat produced by eleetrieity. As we know, there are also many beneficial effects. The heat produced by electricity has contributed much to our comfort and convenience.

While there are metals such as copper, brass, and iron that will either melt or decompose when exposed to a high intensity of heat for extended periods of time, there are others that time and temperature will not materially affect. There are two metals in particular, tungsten and Nichrome, that are especially suited as heating elements. Tungsten is an element having a very high resistance and is used to make the filaments in all types of light bulbs, including fluorescent lamps.

Because of its high resistance, a very small filament of tungsten cannot be connected directly to a 120-V source without blowing a fuse. Instead, only a small electric current is allowed to pass through the resistance of the tungsten filament. A wattage of, say, 100 W is consumed at the filament in the form of heat. Another property of tungsten, its ability to withstand high temperatures, permits this heat to raise the temperature of the filament to incandescence, producing light.

Nichrome is an alloy of nickel and chrome having a resistance which is relatively high but considerably lower than tungsten. Although there may be a few exceptions, Nichrome is used to make all types of heating elements for applications where heat only is desired. Tophet "A" is another metal that is popular for heating elements; it has much the same characteristics as Nichrome.

In the case of a Nichrome heating element, the resistance is spread over a nichrome wire of several feet in length. This element is usually coiled so as to concentrate the heat produced along its length. Where heat is the desired end product, the size and length of the Nichrome wire is such that its resistance, when connected across 120 V, allows a substantial current to flow. The higher current develops a relatively high wattage, resulting in a high output of heat. As can be observed, the heat is sufficient to cause the element to become red-hot. If we apply Ohm's law and the power equation to this explanation, we find that the lower the resistance of the element, the greater the wattage in heat produced. This brings up a very pertinent question: Since the copper wire used to supply the 120 V to the heating element has almost no resistance, why does it not get hot? The reason the lead wires do not get hot is that there is no voltage drop (power consumed) throughout their length.

The voltage at the heating element is the same as that at the fuse box. There are no significant losses and therefore little or no heat produced in the leads. Actually, if a piece of copper wire were placed directly across the 120-V supply, it would pass an extremely large amount of current. The heat produced would burn the wire in two or blow a fuse. It can generally be stated that a voltage drop takes place wherever there is a significant resistance in the circuit. The wattage produced at that resistance is equal to the voltage drop multiplied by the amperage flowing in the circuit. For example, a heating element connected to a 120-V supply which draws 10 A will develop 1,200 W of heating. If heat is to be produced only at the heating element, all connections must be tight. Let us analyze the same heating element in a circuit when one of the connections to the element is loose. Let us assume that the resistance of the loose connection

measures only $\frac{1}{10}$ Ω. That is not very much compared to the resistance of the heating element. In fact, it will scarcely affect the current flow in the circuit. Applying Ohm's law, 10 A of current flowing through $\frac{1}{10}$ Ω of resistance will produce a voltage drop of 1 V. This, too, is not very much, but the 1 V multiplied by the 10 A of current equals 10 W of heat developed at the loose connection. This much heat concentrated at such a small point will raise the temperature of the loose connection to the point where the connection will burn. From this it is easy to see why it is so important that all electric connections be tight.

Let us now consider heating elements such as those used in electric ranges. In selecting the size and length of a heating element to use in an oven, three heat factors must be considered:

1. The amount of current or amperage
2. The resistance of the conductor
3. The length of time current flows

At a given voltage, the lower the resistance of the conductor, the higher the amperage in that conductor. The higher the amperage at a given voltage, the greater the amount of heat produced in the conductor. Therefore, there must be a proper balance between the voltage, amperage and resistance in order to control the amount of heat desired.

The time factor is of considerable importance in designing heating elements for cooking food. There has to be a proper relationship between time and temperature. Foods vary in the length of time they must cook at a certain temperature. For example, a cake may require 30 min at 350° to bake properly. This does not mean that it will bake properly in 15 min at 700°. It would only burn on the outside and be unbaked in the center. The designer of oven heating units, therefore, must consider the time factor as well as the other factors.

Watts versus heat. An important consideration that must be given in designing an oven unit is the wattage consumed by the element in relation to the amount of heat produced. For every watt consumed, 3.42 Btu of heat are produced for every hour the element is energized.

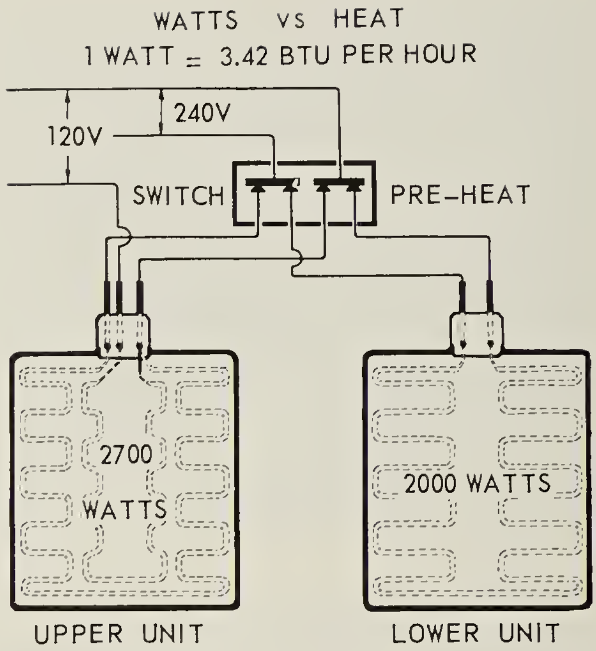


Figure 7-23. Illustration to show the relationship of watts versus heat.

Two oven units used in an early model range are illustrated in Fig. 7-23. This model had a preheat feature which increased the oven temperature to a preset baking temperature in approximately 7 min. The range engineers knew that in order to bring the oven from room temperature to a desired preheat temperature in a relatively short time a certain number of Btu had to be given off by the heating elements. Therefore, on the basis of the 3.42 Btu/Wh, the size and length of the Nichrome wire required to consume the necessary wattage at a predetermined voltage was determined.

In tracing the circuit through the two units it is apparent that when 240 V are applied to the lower unit, the resistance is such that power is consumed at the rate of 2,000 W. In the upper unit, two separate elements are employed. The outer element with 240 V applied consumes 1,800 W, and the inner element with 120 V applied consumes power at the rate of 900 W, for a combined total of 2,700 W. In 1 min, with both upper and lower units consuming

power at the rate of 4,700 W, 267 Btu of heat will be produced (4,700 × 3.42/60). At this rate the oven will reach its baking temperature in about 7 min.

Naturally, at this rate any food in the oven would soon burn on the outside without cooking on the inside. The engineers designed the control so that after the preheat, the temperature is automatically reduced to the desired degree for proper baking results. From experience, it has been found that with the lower unit at full heat, only a small amount of heat from the upper unit is required.

The heating units used in present ovens are rated much higher. The bake unit is rated at 3,000 W, and the broil unit is rated at 3,200 W. For baking, the broil units are supplied with 120 V. This produces only 800 W. This, together with the 3,000 W produced by the bake unit, operating on 240 V, provides a total of 3,800 W. This is sufficient to bring the oven up to temperature quickly and is properly proportioned to produce finest baking results.

Watts versus volts. Since watts are the product of volts times amperes, it can be seen that any change in voltage will change the wattage. In Fig. 7-24, the two oven units are shown with the switch in the BAKE position. Tracing the circuit shows that full heat is being produced by the lower unit, because the 240 V keeps the power flowing at the rate of 2,000 W. The upper unit, however, has power flowing at the rate of only 300 W. This is accomplished by a switching arrangement in the control which directs the 120-V current through both the inner and outer elements in series.

It is an established fact that when the voltage through a pure resistance is halved, the wattage is quartered. For example, if we connected the lower unit to a source of 120 V instead of 240 V, the watts would be reduced from 2,000 to 500. The reason that 675 W (one-quarter of 2,700) is not consumed in the upper unit is because the entire unit is not designed for 240 V. Putting Ohm's law and the power equation to work, it is easy to determine how the engineer got 300 W

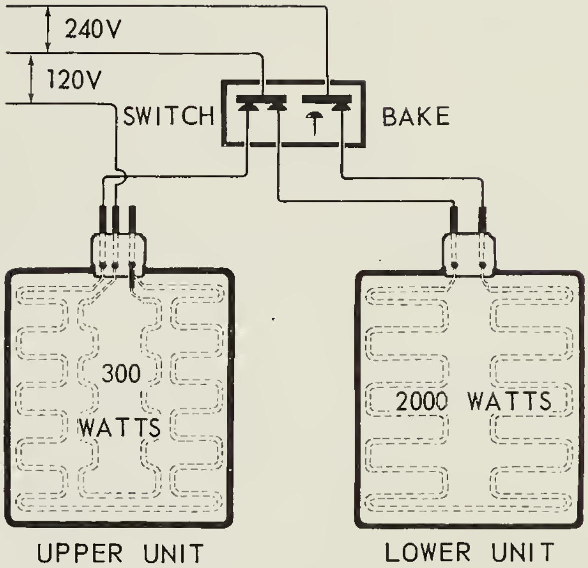


Figure 7-24. Illustration to show the relationship of watts versus volts.

in the upper unit. In either equation, as long as two of the factors are known, the third can be found. Let us start with the outer element. It is known that the outer element is rated at 1,800 W at 240 V. According to the power equation, $I = P/E = 1{,}800/240 = 7.5$ A. Since the amperage and voltage are known, Ohm's law may be used to find the resistance. $R = E/I = 240/7.5 = 32\ \Omega$.

On the same basis, the inner element can be computed. $I = P/E = 900/120 = 7.5$ A. The resistance then is $R = E/I = 120/7.5 = 16\ \Omega$. Now, the necessary information is at hand to solve the problem. Earlier it was learned that in a series circuit the total resistance was equal to the sum of all resistance. Therefore, the total resistance is $32 + 16 = 48\ \Omega$.

We also learned that the current is the same through each part of the circuit. Since the volts and total resistance are known, Ohm's law tells us again that $I = E/R = 120/48 = 2.5$ A. The final answer can now be figured by applying the power equation again. $P = E \times I = 120 \times 2.5 = 300$. Using this heating element as an example, the effect of voltage on the wattage of a heating element can be readily seen.

LIGHTING FOR APPLIANCES

Both incandescent and fluorescent lights are used in appliances. That is, we have pilot lights, indicator lights, safety lights, cabinet lights, etc. When a replacement is necessary be sure to use the proper size and type of lamp or bulb as recommended by the appliance maker.

Incandescent-bulb circuits are simple and are easy to check out. Only the switch (either manual or mechanical), the bulb, the socket, and the wiring can be at fault. Three additional major components are used on fluorescent-lighting systems: the lamp, the starter, and the ballast.

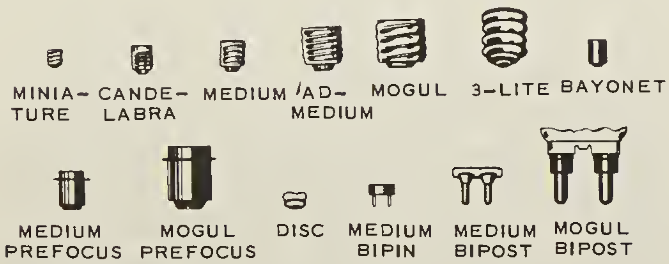
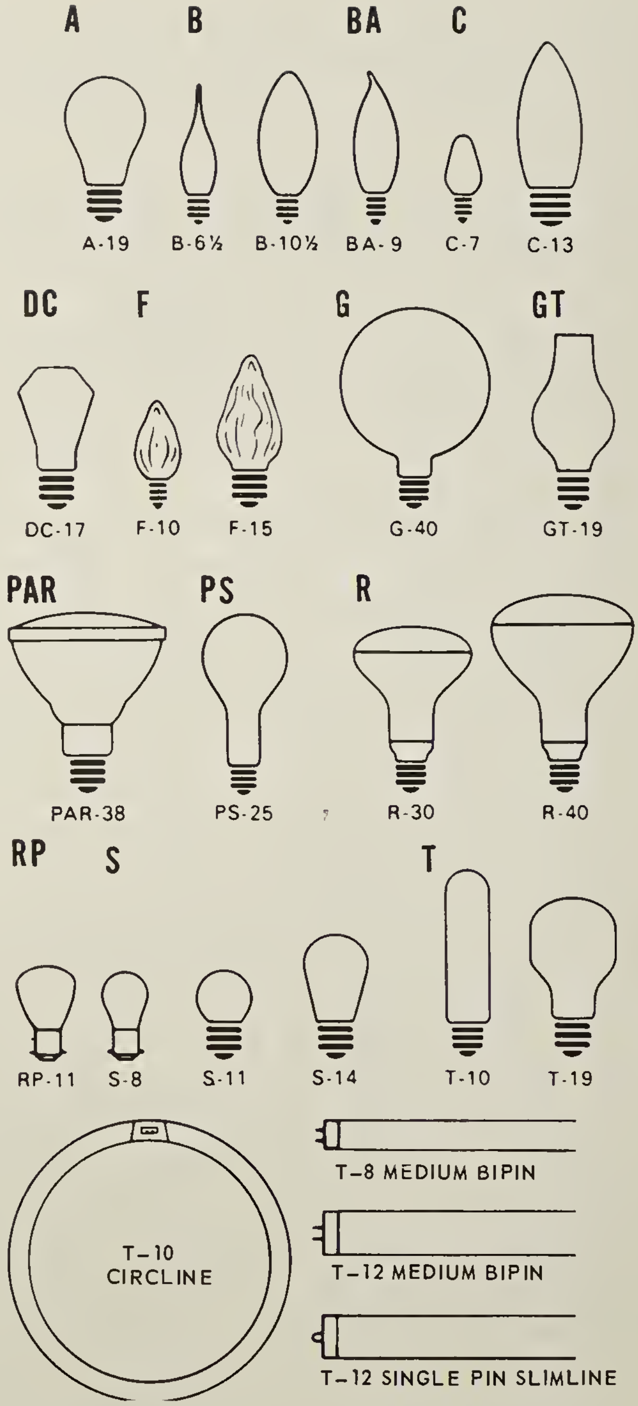


Figure 7-25. Lamp bases used in appliances.



BULB SHAPES

BULB DESIGNATIONS. THE LETTER IN A BULB DESIGNATION INDICATES THE SHAPE, WHILE THE NUMBER INDICATES THE APPROXIMATE DIAMETER IN EIGHTHS OF AN INCH. THUS T-8 IS A TUBULAR BULB APPROXIMATELY ONE INCH IN DIAMETER.

Figure 7-26. Lamp sizes and shapes.

The *lamp* consists of an internally phosphor-coated tube filled with mercury vapor and contains a filament at each end. Light is produced when the gas is ionized (conducts current). Ultraviolet radiation is produced by the passage of current through the gas between the two filaments. The phosphor coating is activated by the ultraviolet radiation and in turn reradiates visible light. When the gas becomes ionized, its resistance decreases as current passes through it. If current is allowed to continue to flow unchecked the lamp will burn out. The ballast is placed in series with the lamp to limit the current flow.

The *starter* consists of switch contacts mounted on bimetal strips enclosed in a glass bulb filled with gas. The gas ionizes at approximately 75 to 80 V. Most starters also contain a small capacitor to eliminate radio interference. The starter is used to automatically break the circuit between the filaments after they become heated.

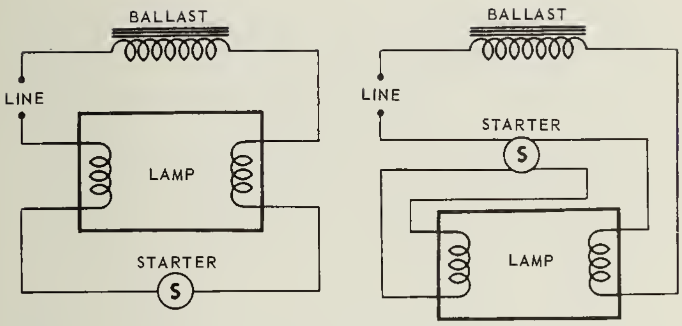


Figure 7-27. Fluorescent lamp operation using ballasts.

The *ballast* is an inductive load which performs two functions:

1. It provides the inductive voltage surge, which is necessary to fire, or ionize, the gas in the fluorescent lamp.
2. It serves as a current limiter to prevent the flow of excessive current through the fluorescent lamp.

Fluorescent lamps are used in ranges, clothes washers, and dryers and there are two basic types of switches employed: manual and automatic. Let us check the operation of a typical manual controlled fluorescent lamp in a 30-in range model.

1. The lamp switch is closed by depressing the lamp-switch plunger.
2. When the lamp switch is closed, a potential of 120 V is placed across the starter. The gas in the starter becomes ionized and current flows through the entire lamp circuit. The gas in the starter ionizes at approximately 75 to 80 V.
3. The current flow through the ionized gas in

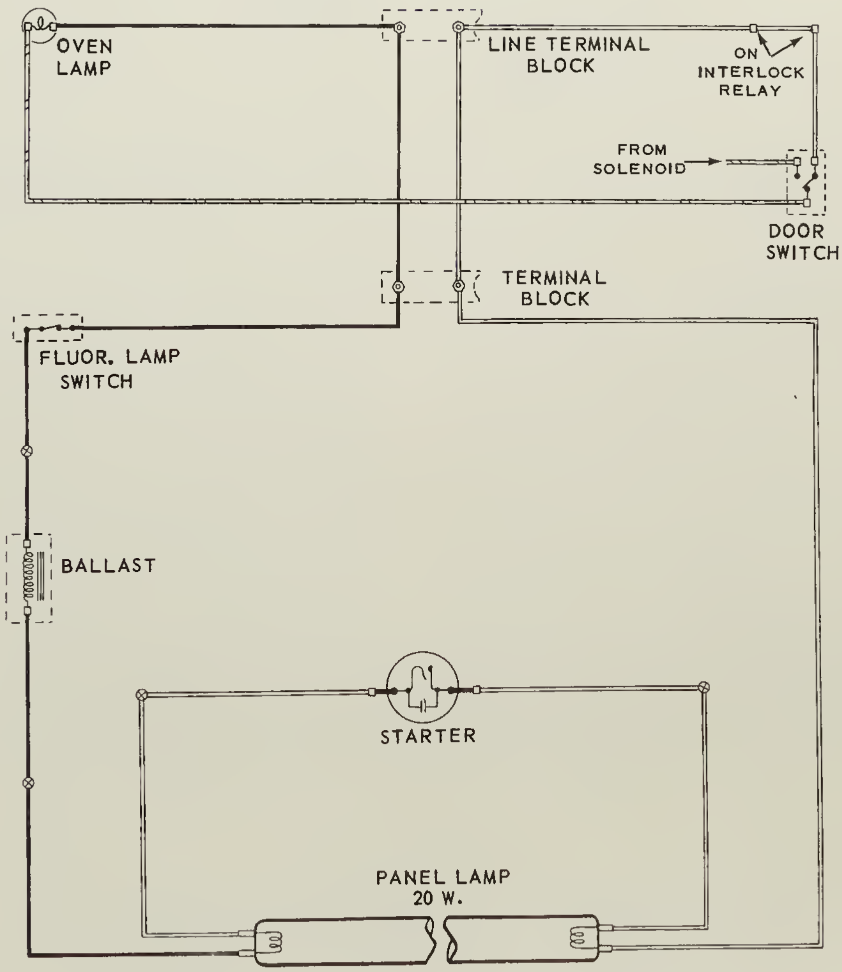


Figure 7-28. Schematic diagram of fluorescent lamp in a 30-in range model.

the starter heats the bimetal strips, causing them to bend and close the starter contacts (Fig. 7-28).

4. The current flow through the filaments within the fluorescent tube heats them and prepares the gas in the tube for ionization.
5. When the starter contacts close, the gas in the starter becomes deionized. The bimetal strips cool and the starter contacts open.
6. When the starter contacts open, the current through the ballast is cut off, giving an inductive surge. The inductive surge is produced by the collapse of the magnetic field around the ballast. This voltage surge, added to the 120-V line voltage, is applied across the fluorescent tube.
7. The gas in the fluorescent tube, having been heated by the filaments, is ionized by the

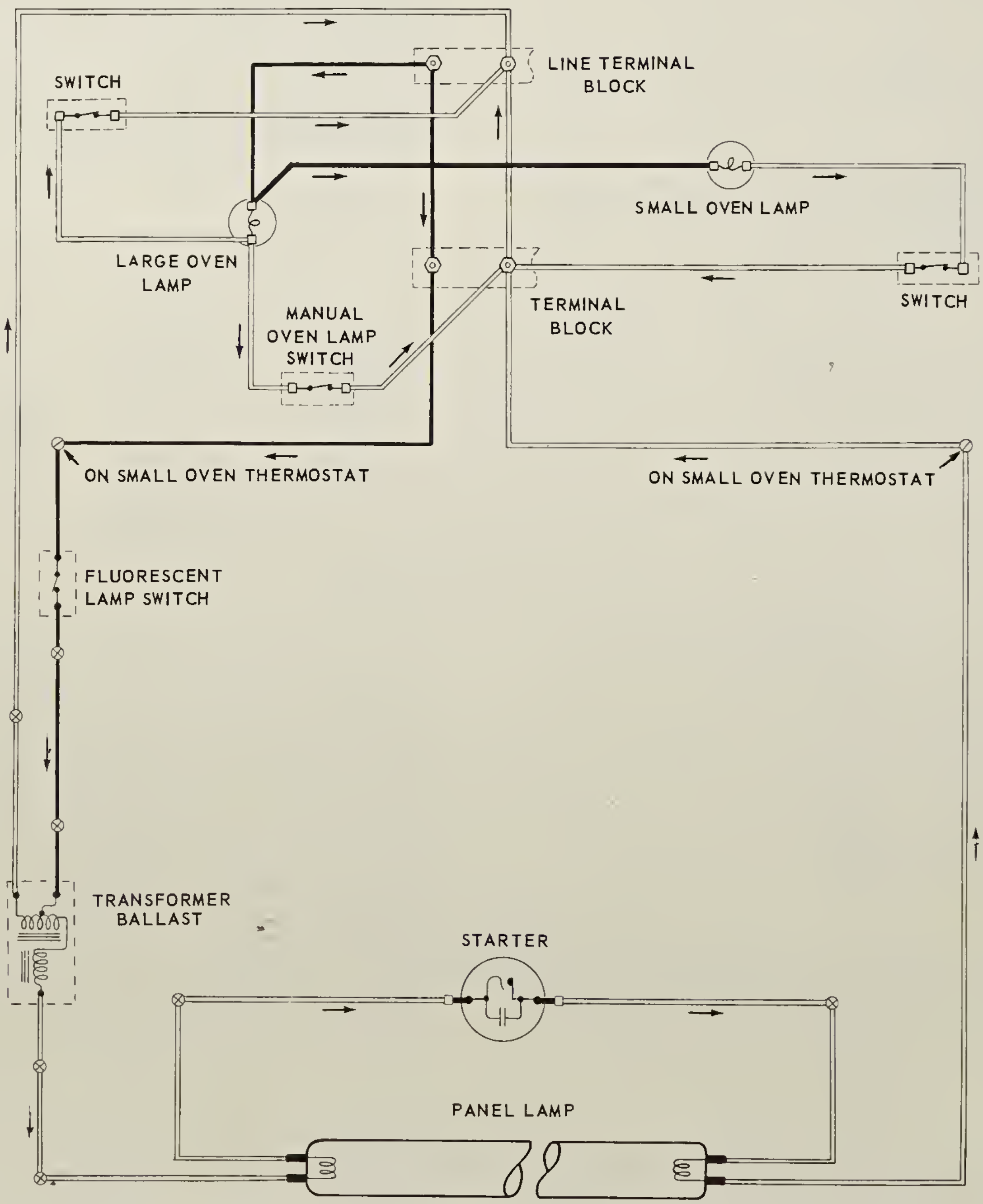


Figure 7-29. Schematic diagram of fluorescent lamp in a larger range.

line voltage plus the ballast voltage surge. The voltage drop across the lit fluorescent tube is approximately 55 V.

8. The starter is designed so that the gas will not become ionized at a voltage of less than 70 V, so that the starter will not operate or become ionized while the fluorescent tube is lit.

For larger ranges, a longer bulb rated for higher wattage is usually required (Fig. 7-29). As a general rule, the voltage surge, or kick, needed to force the starting arc of electricity across the lamp increases as the lamp gets longer and/or the diameter of the lamp becomes smaller. This requires the usual 120 V to be raised to approximately 220 V to provide positive starting and is accomplished by the addition of a step-up transformer winding to the basic ballast circuit.

The most widely used automatic switches are of the glow type, shown in Fig. 7-30. The heart of this device is a small glass bulb containing neon or argon gas. There is a U-shaped bimetallic strip and a fixed contact inside the bulb. When the current is turned on, the voltage between the bimetallic strip and the fixed contact is high enough to make the gas glow, as shown in Fig. 7-30A. The heat from the glow causes the strip to bend and make contact, as in Fig. 7-30B, and close the circuit so the filaments preheat. This also shorts out the glow discharge so that the bimetal strip cools and, in a few seconds, the contacts open, as shown in Fig. 7-30C. The inductive kick from the ballast starts the lamp: During normal operation the contacts stay open until the lamp needs to be started again.

If the lamp fails to start, the starting cycle is repeated over and over again. If the lamp is defective and will not start, the starter will fail in a short time. To avoid this, some glow switches have a manual reset. This operates the same as the standard glow switch but has a spring trip mechanism that opens the switch if the lamp fails to start within 15 or 20 s. If you replace a defective lamp, you should reset the starter by pushing the button on top of the starter.

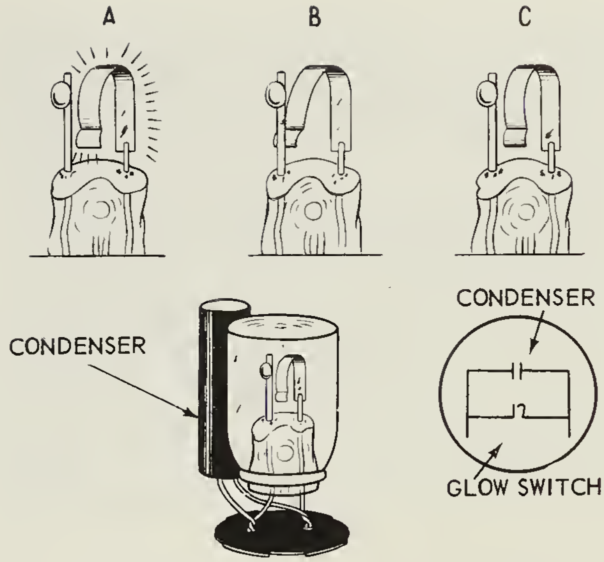


Figure 7-30. Operation of a glow-switch starter.

Indicator lights. Neon lamps are usually used as indicator lights. Like the fluorescent lamps you have already studied, neon lamps have one very important operation characteristic: They do not limit the current that goes through them. Unless there is some current-limiting device connected into the lamp circuit, the current will increase until it destroys the lamp. For this reason, a small resistor is placed in series with the neon lamp and allows only a very small current to pass. If there is even a small amount of moisture in the thermostat housing or handle, the heat will vaporize it and some of it may get on the resistor. If enough moisture gets on the resistor—it does not take much—the resistor will short out or be so reduced in value that there will be little or nothing to limit the lamp current and the lamp will burn out.

Test equipment and tools

CHAPTER

8

In the field of appliance servicing, accurate quantitative measurements are essential. This involves two important items—numbers and units. Simple arithmetic is used in most cases, and the units are well defined and easily understood. The standard units of current, voltage, and resistance, as well as other units, are defined by the National Bureau of Standards. Manufacturers of various instruments calibrate them by comparing them with established standards.

Appliances are designed to operate at certain efficiency levels. To aid the technician in maintaining the appliance, technical service-instruction manuals, schematic drawings, parts lists, servicing data, and optimum performance data such as voltages and resistance are prepared for each appliance by the manufacturer. Before servicing an appliance you should, if possible, check its service manual. It will save time in the long run.

To the technician, a good understanding of the functional design and operation of electric instruments is important. In appliance service work one or more of the following methods are commonly used to determine if the circuits of an appliance are operating properly.

1. Use an ammeter to measure the amount of current flowing in a circuit.
2. Use a voltmeter to determine the voltage existing between two points in a circuit.
3. Use an ohmmeter to measure circuit continuity and total or partial circuit resistance.

The technician may also find it necessary to employ a wattmeter to determine the total power being consumed by certain equipment.

A thorough understanding of the construction, operation, and limitations of electric measuring instruments, coupled with the theory of circuit operation, is most essential in servicing and maintaining electrical appliances.

TEST EQUIPMENT

Test instruments are designed to make diagnosis and repair faster, easier, and more accurate. This means more profit for the repair company and satisfaction for the customer. Good tools may amount to a sizable investment, but they are not expensive in the long run if carefully selected, properly used, and conscientiously maintained. We will discuss selection, care, and use of some of the more popular pieces of test equipment used in appliance service.

When selecting test equipment for your use, sit down and list the features that you *must* have, those you would *like* to have, and those that you can do without. Careful shopping will probably produce an instrument reasonably close to what you want.

Figure 8-1. Various types of multimeters.

Now—is it less expensive to purchase one instrument for most functions, or to purchase several instruments, each with a particular function? One instrument is easier to carry, if it is not too bulky, but it will be rather complex and it will take practice and study to learn to use it to its full capacity. Carrying several instruments has the possible advantages of easier reading, less initial expense per unit, and the fact that you will still have some type of test equipment should one meter be in the shop for repair.

Multimeters, instruments that have more than one function, have either a selector switch or several test-probe plug-in positions which are arranged in groups—voltage positions, ohm positions, etc. Each switch or probe position relates to one particular scale on the meter face. Reading the wrong scale can result in an inaccurate diagnosis. When selecting a multimeter, keep in mind that the meter case should be resistant to breakage and should protect the delicate meter and other components from dust, dirt, and grease.

When shopping for an electric test instrument,

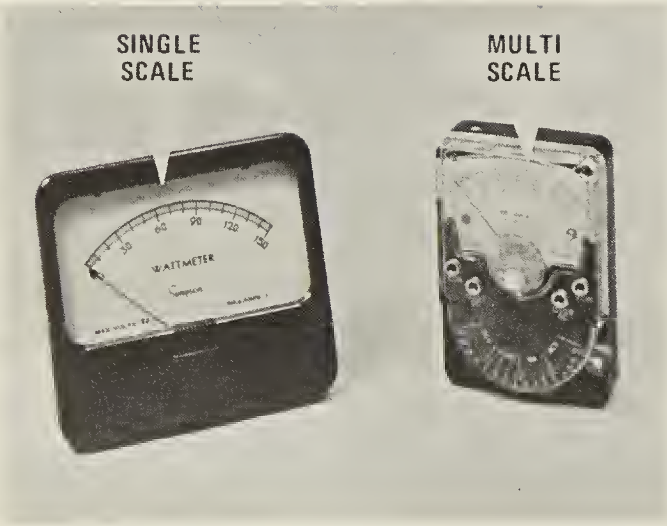


Figure 8-2. Single-scale and multiscale test instrument.

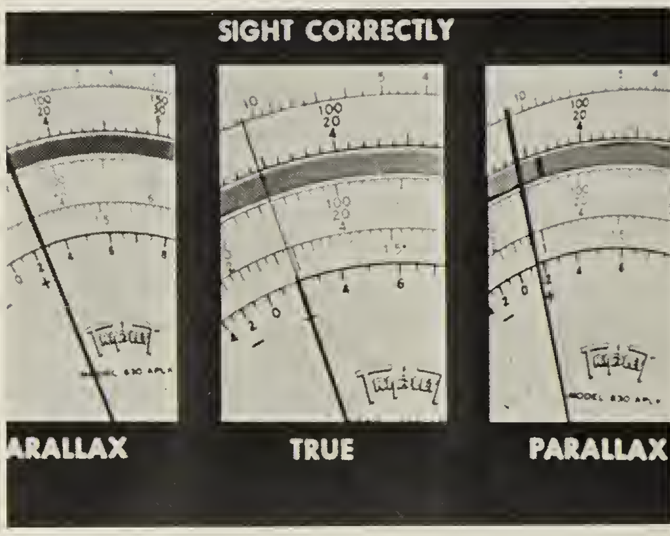


Figure 8-3. Parallax is a problem if you do not look straight.

select one with a good jeweled or taut-wire movement. Field-test equipment need not be as accurate as that used in laboratories, but an instrument with a sticking needle or with a calibration screw that drifts with usage is of little value. If you expect to use your test equipment for electronic diagnosis, it will be necessary to invest in more sensitive equipment. High-impedance meter movements with 20,000 Ω/V dc resistance or greater should be used.

When selecting a test instrument, look for one with a meter face that is easy to read. Single-function instruments with large meter faces are, of course, easier to read and interpret than small multimeters; the multiuse instrument has the advantage of having many diagnostic functions contained in one highly portable package.

Meter scales are either linear or nonlinear, depending on the intended function. The divisions on a linear scale are evenly spaced (as on a yardstick). Nonlinear markings (divisions spaced as on a slide rule) are difficult to read on a small meter face. Select an instrument where the readings that you expect to work with will be at or near midscale, both for ease of reading and accuracy. Accuracy is lost at either end of the scale. Parallax is another source of inaccuracy. When reading a meter look straight at the meter face. The three instruments shown in Fig. 8-3 are all actually indicating 75 V ac, but two are being seen from an angle. Some test meters have a mirror imbedded in the meter face. When there is no reflection of the needle seen in the mirror, you have eliminated parallax and are at the proper angle for an accurate reading.

Even with instruments that we have owned for a long time, we tend to forget some capabilities or limitations. It is advisable to periodically review the owner's care and use manual for each instrument you use. If you do not have one, contact your dealer. If spare time is available, an interesting project is to construct some of your own test equipment from kits that are available through several suppliers. You not only have the pleasure of constructing something useful, but you also become more familiar with the instrument and learn to respect and care for it. But remember that no matter how much you feel that you need an instrument, if you are not going to use it and learn to use it properly—do not buy it. Some very necessary instruments will be used rather infrequently due to their application.

Care of test instruments. All instruments should be checked for accuracy periodically. If the owner's manual does not give you step-by-step instructions on this, the meter should be

Figure 8-4. Always position a meter before zeroing.

taken to an authorized repair station for inspection.

Most meter movements are position-sensitive. They are most accurate when placed in a horizontal position or nearly so. The instrument should be in its in-use position when calibrating or "zeroing" the needle—as shown in Fig. 8-4. All instruments have a specific point at which the needle should rest when the instrument is not in use, which is called the *null* point.

Inspect test leads regularly for wear or deterioration of the insulation. Replace them when the first sign of failure is apparent. Some leads can be easily replaced by standard probes purchased at a local electronics supply house—others are special and can only be replaced with leads supplied by the instrument manufacturer. Firm, solid contact should be made when the leads are connected to the instrument. Loose-fitting leads can cause improper readings on the meter.

For our purpose, we can look upon the mechanism that drives the needle across the meter face as a motor. This or any other motor can be damaged by improper lubrication, rough handling, or overloading. In other words, treat test instruments with respect. They should not be subjected to the beating received in a toolbox. Extremes of hot and cold are not good for any tools, especially meters. Oil, dust, and moisture should be kept away. Test meters carried in the field should be kept in protective cases. Always keep in mind that if an instrument is used for its intended purpose, it will last indefinitely.

The fuses or circuit breakers found in many new instruments are designed to prevent permanent damage to the instrument should the movement become overloaded. If your instruments are "fused," carry spares.

Use only high-quality batteries in a test instrument and check them frequently for corrosion. Some batteries will leak acid and ruin a meter even before all power is lost. It is good to make a list of all instruments containing batteries, mark the calendar, and once a month make a careful inspection. On instruments used infrequently, remove the batteries and store them separately. Some manufacturers do not recommend metal-clad batteries for use in their instruments.

The selector switch on a test instrument should never be left turned to a position that calls for battery output. This hastens battery failure. In the absence of a selector switch, all leads should be kept disconnected except when the instrument is in use. Let us discuss some specific types of instruments and list a few of the features.

Types of Instruments

Voltmeters. The voltmeter is probably one of the most-used instruments and the simplest to read. You may be dealing with anything from millivolts (one-thousandth of a volt) to over 5,000 V, so reasonable care should be exercised.

When using a voltmeter, select the proper setting on the function switch for the voltage you expect to read. When in doubt, to protect the meter from damage, start with the highest voltage scale and work down until near-midscale readings are obtained. For safety's sake, when dealing with line voltage, first disconnect the appliance, connect the test probes with alligator clips, then reenergize the appliance and take the voltage reading. Often this is neither possible nor practical. In any event—be careful!

The voltmeter must be connected in parallel

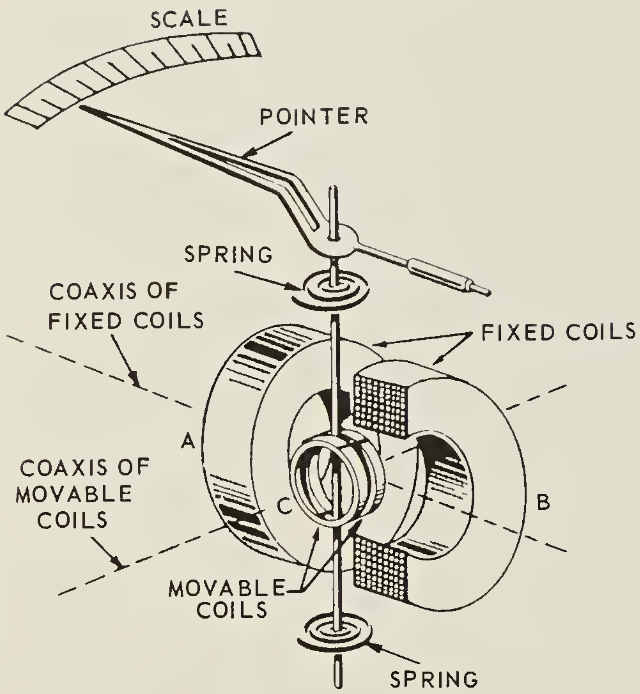


Figure 8-5. Inside construction of a test meter.

with the load or portion of a circuit to be read (Fig. 8-6). Whatever is recorded on the meter is the voltage that is dropped between connected test probes. The voltmeter can also tell us much about the operation of the circuit. For example, when the meter is connected across a switch and indicates the voltage supplied to the circuit, the switch is open (not conducting current). Should there be no voltage drop across the switch, and no other switches are open in the same circuit, the meter would tell us that the switch is closed (it is conducting current). A partial voltage drop across a switch would tell us that the contacts are not fully closing and there is resistance within the switch.

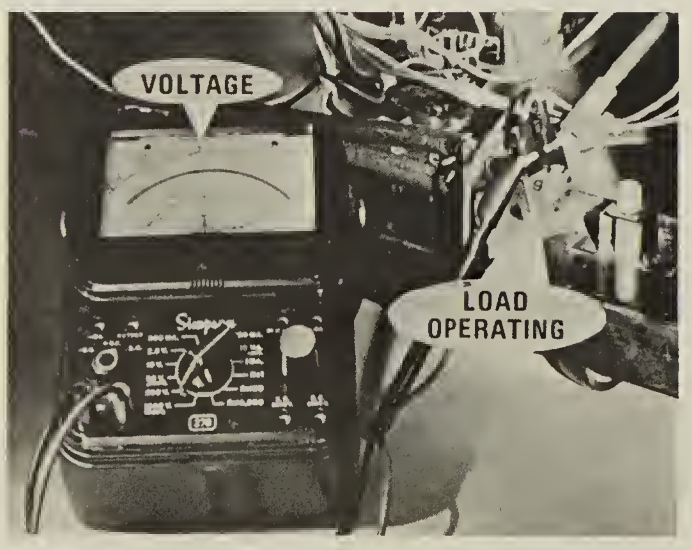


Figure 8-6. The voltmeter must be connected in parallel with the load or portion of a circuit to be read.

When testing for low voltage to a motor, the test should be made as close as possible to the load and should be made at the instant of start, when the load is heaviest. (Voltage at this point should always be within 10 percent of what the load is designed for. The only exception is on 240/208-V equipment. Voltage must be within 5 percent when applying 208 V.) Care should be exercised when making running-voltage checks on a motor. Unused windings in a multispeed motor or starting windings that are switched off after the motor comes to speed can give a reading far in excess of input voltage due to induction from the in-use windings. Many meters have been damaged because the test voltage exceeded the voltage scale selected on the meter.

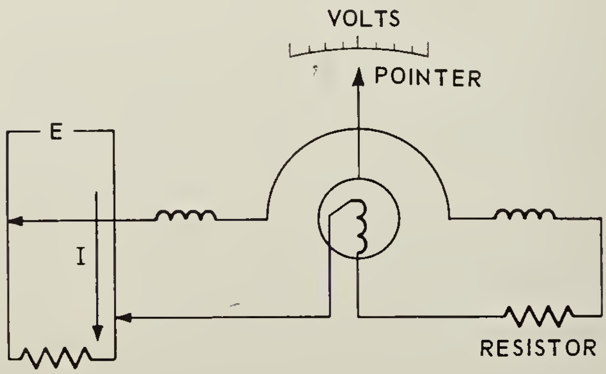


Figure 8-7. Circuit arrangement of voltmeter.

When testing millivoltage (1 mV $= \frac{1}{1{,}000}$ V), the thermocouple should be connected to the power element through an adapter in order to obtain a closed-circuit or under-load reading. Open-circuit readings on thermocouples are generally worthless unless they are compared to

load conditions by a charted curve, which may be available from the part manufacturer.

Do not attempt to read ac voltages when the instrument is set for dc, or vice versa. When measuring dc and the needle deflects to the left, either reverse the test leads or, if the instrument is so equipped, reverse the polarity switch.

Ohmmeters. The ohmmeter is used for measuring resistances, checking continuity, making quick checks on capacitors, and testing certain solid-state components.

One of the greatest causes of meter damage in the field is to connect an ohmmeter to a circuit or component that has not been disconnected from a source voltage. An ohmmeter has its own source of power and *cannot* safely be connected to any other.

Before using an ohmmeter, perform the following steps to tell whether it is in proper operating condition:

1. With the test leads unplugged, set the range switch on the desired resistance scale. The needle should be stationary at the infinity mark. The symbol for infinity is the "lazy eight" (∞). Small adjustments of the needle position can be made by turning the screw directly under the needle pivot point. If the needle is very far off, the meter may be in need of repair. Sometimes the needle will change position slightly if the meter is laid on its back or changed to an upright position.
2. Plug in the test leads. The meter has two color-coded leads, one red and the other black. The red lead is used in the positive (+) jack; the black lead is used in the negative (−), or common, jack.
3. Touch the tips of the leads together. The needle should move to the zero position to indicate zero resistance.
4. If the needle is not at zero, turn the zero (Ω) adjust knob one way or the other to bring the needle into position. This operation is called "zeroing the ohmmeter." If the ohmmeter is being used for making several tests or for long periods of time, it will be necessary to re-zero it from time to time. It will also be necessary to check for zero whenever range scales are changed. If the needle cannot be zeroed when the probes are shorted together, the meter needs new batteries.

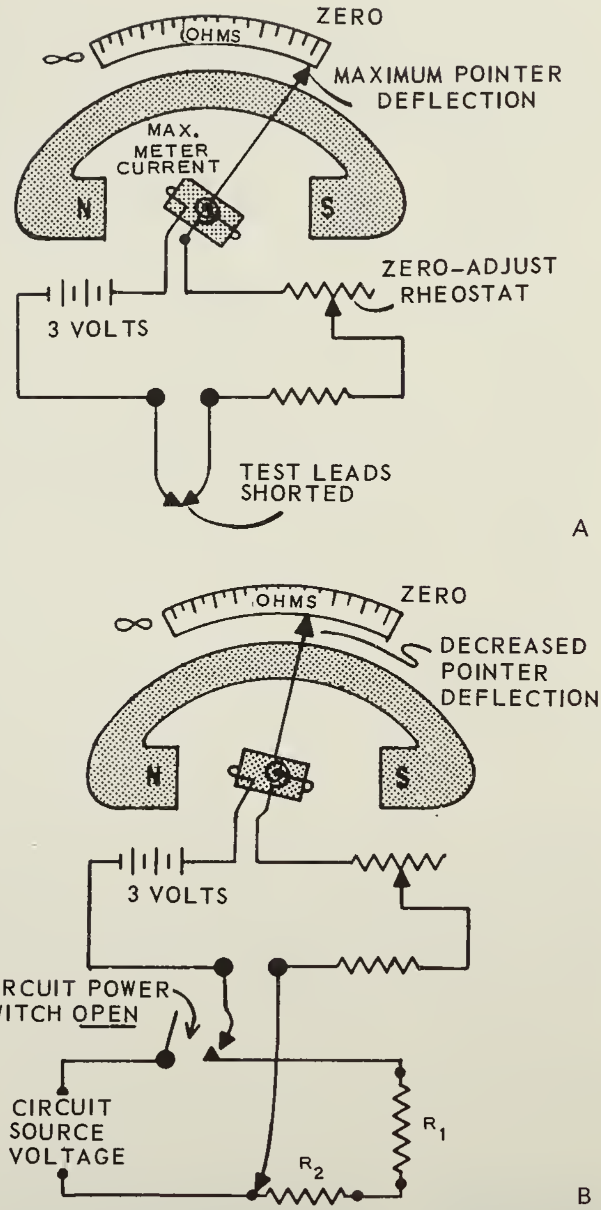


Figure 8-8. (A) Simple ohmmeter circuit; (B) measuring circuit resistance with an ohmmeter.

When measuring a resistance, the range switch should be set to positions marked R × 1, R × 10, R × 100, or R × 1,000. The value of a measured resistance is the needle reading multiplied by the multiplier setting of the range switch. When

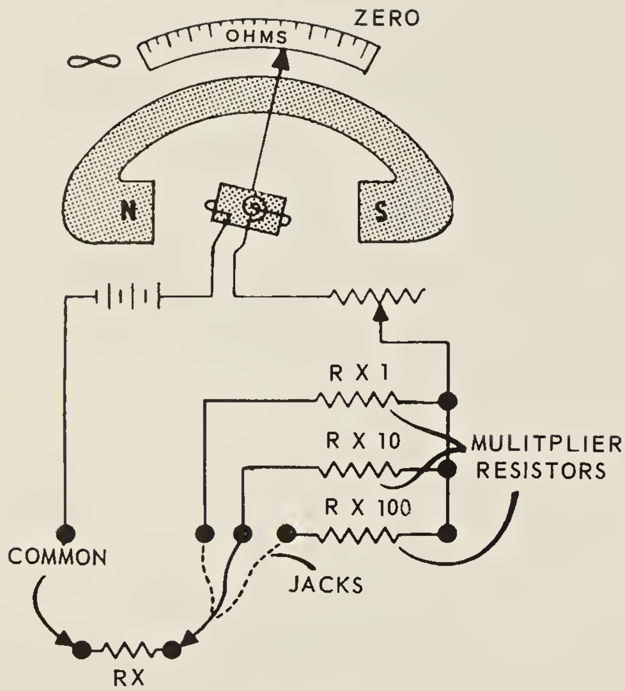


Figure 8-9. Ohmmeter with multiplication jacks.

testing for continuity, or when measuring an unknown resistance, it is best to start with the *lowest* resistance scale and work up through the ranges until (when measuring resistance) a mid-scale reading is obtained.

Be sure that all power is off to the appliance

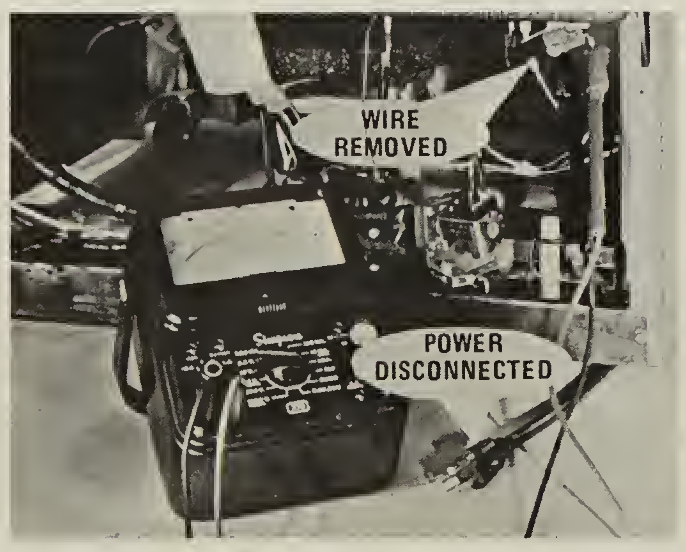


Figure 8-10. Be sure that all power is off to the appliance being tested with an ohmmeter.

being tested (Fig. 8-10). Isolate the component or portion of the circuit that you wish to test by disconnecting the component at one or both ends. This prevents the accidental reading of other circuits in parallel with the one being tested. An ohmmeter, like a voltmeter, can tell a great deal about a component or circuit. For instance, when testing a switch or wire for continuity, a full deflection of the needle to zero indicates a closed switch or circuit; the item being measured has continuity. Should the needle not move from its AT-REST position, the switch or circuit is open. The item does not have continuity, and the resistance is said to be infinite. Anytime the needle comes to rest at a spot between infinity and zero, we are recording the measurable resistance of the circuit or component. Check timers the same way as switches; that is, check across each set of contact points with the ohmmeter.

When testing for grounded windings in a motor or compressor, set the ohmmeter to read high resistance, properly zero the needle, connect one probe to bare metal on the motor frame, and touch the other probe to each of the motor input terminals after the input wires have been disconnected. Any reading less than infinity indicates a short or a leak to ground.

An ohmmeter can be used to locate the common, start, and run terminals on most motors. The highest resistance will be found between the start and run terminals, the lowest resistance between the run and common, and the middle resistance between common and start.

To check a thermostat with an ohmmeter, check for continuity between the terminals. Remove the lead wires, turn the thermostat to its high-limit setting, and connect the ohmmeter. No reading indicates a defective thermostat.

When testing for intermittent breaks in a circuit, tap or wiggle the part being tested while watching the meter; when the needle becomes unstable, the problem area has been located.

Most starting and running capacitors can be tested for open or shorted conditions with an ohmmeter. Before testing, however, the capacitor should be disconnected and discharged. To safely discharge the capacitor, connect a

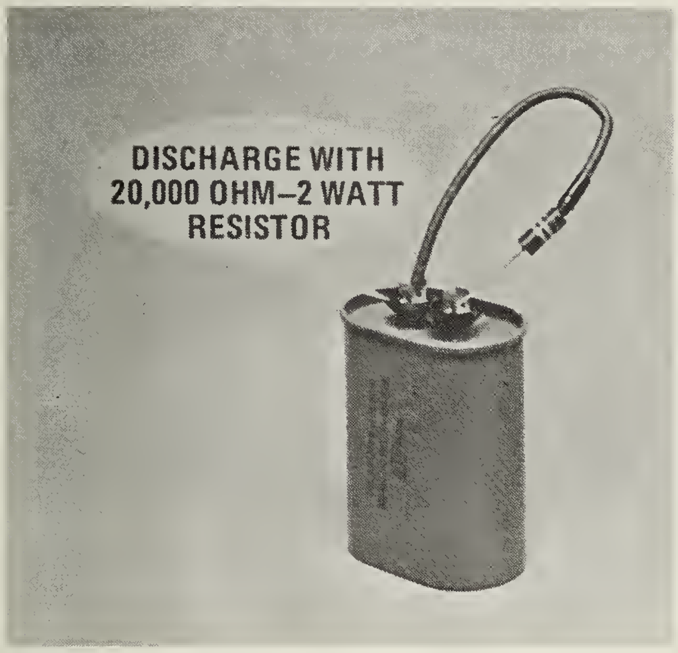


Figure 8-11. Method of discharging a capacitor.

20,000-Ω, 2-W resistor across the terminals (Fig. 8-11).

When a capacitor is open, the needle will not deflect from the infinite or AT-REST position. When shorted, the needle will deflect and remain at or near the zero-resistance point. Capacitance is indicated when the needle deflects toward zero, then returns to the infinite position. Discharge

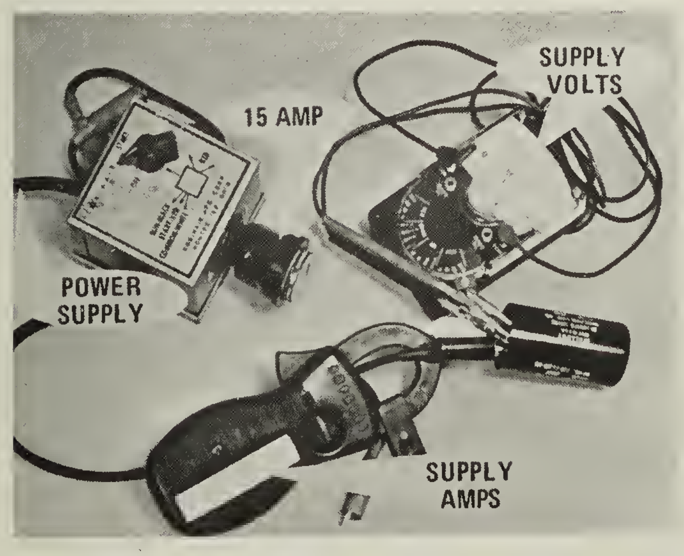


Figure 8-12. Capacitance test on ac 60-Hz arrangement.

the capacitor after each test.

The ohmmeter test does not tell the microfarad capacity of a capacitor. This can be found by using a voltmeter, an ammeter, and a fused test cord with the following formula:

$$\frac{2{,}650 \times \text{amperes}}{\text{ac volts}} = \text{microfarads}$$

Connect the capacitor as shown in Fig. 8-12 and read the input volts and amperes. Multiply the amperage recorded by 2,650 and divide that by the voltage applied to the capacitor. Be careful when testing starting capacitors; they are not designed to be energized in this manner for over 3 s at a time.

Should it be necessary to test solid-state components such as transistors or diodes with an ohmmeter, do not use the higher ranges such as $\times$ 100 or $\times$ 1,000 on standard field-type instruments. To do so could damage the part being tested.

When the ohmmeter is not being used, the selector switch should be turned to the OFF position, and the zero adjust knob should be turned back (usually counterclockwise) to the LOW position. This protects the instrument and the batteries.

When storing an ohmmeter, it is a good idea to remove the leads and wrap them neatly around the instrument. This removes the danger of shorting the leads accidentally. If the leads are shorted while the range switch is on any ohms range, the batteries could run down. Old, run-down batteries should never be left in the meter. Any battery leakage could damage the meter circuits. If the meter is left stored for an extended period of time the batteries should be checked occasionally for possible deterioration. If it is a multifunction meter, it is also a good idea to set the range switch on the highest voltage range.

Ammeters. The *tong ammeter* has become the most popular current-measuring device for ac circuits because it is not necessary to break a line to connect the instrument. Simply clamp the tong around one wire supplying the circuit being tested. Most clamp-on ammeters are designed to measure alternating current only. This instru-

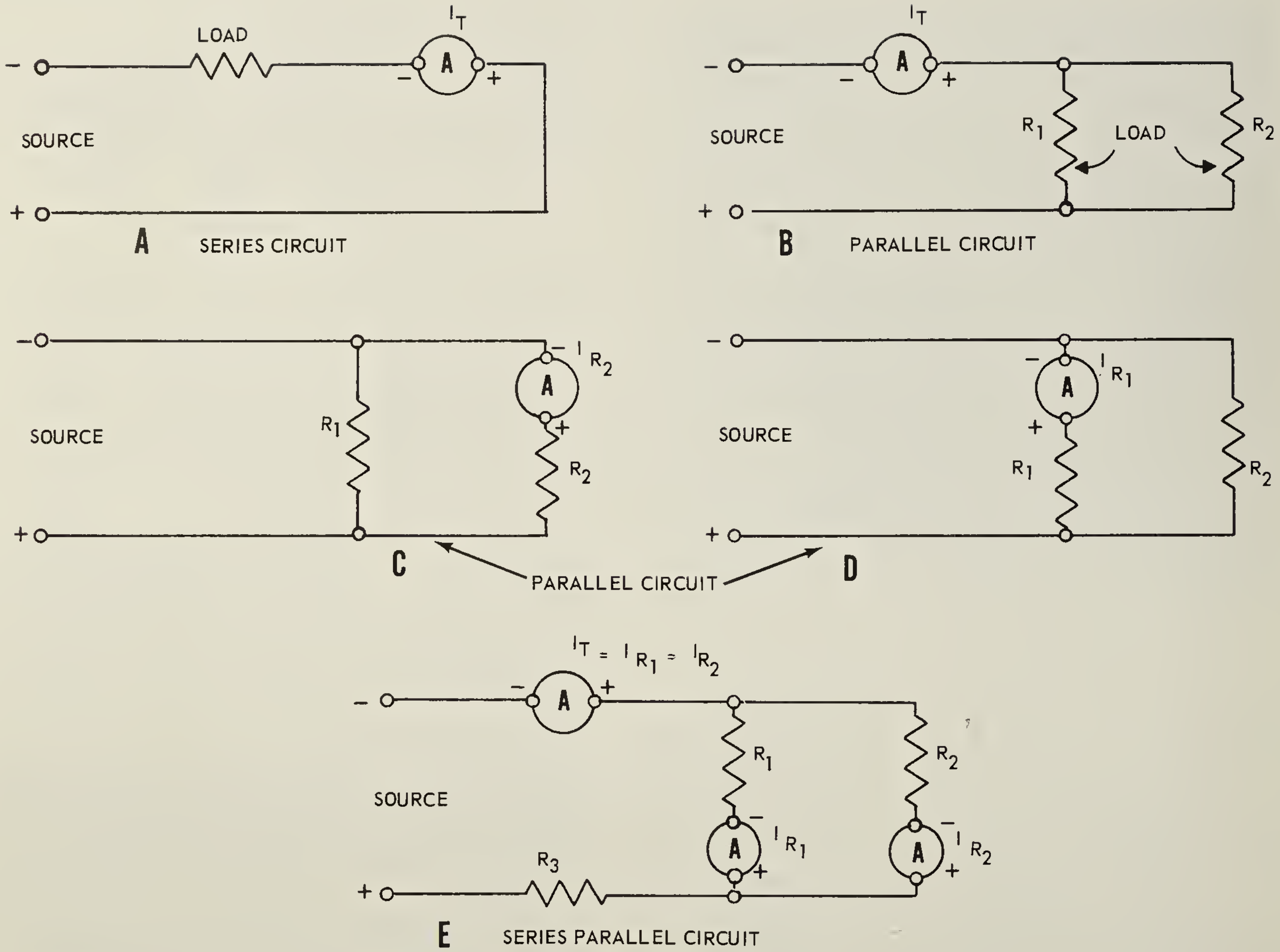


Figure 8-13. Circuit arrangement of ammeter.

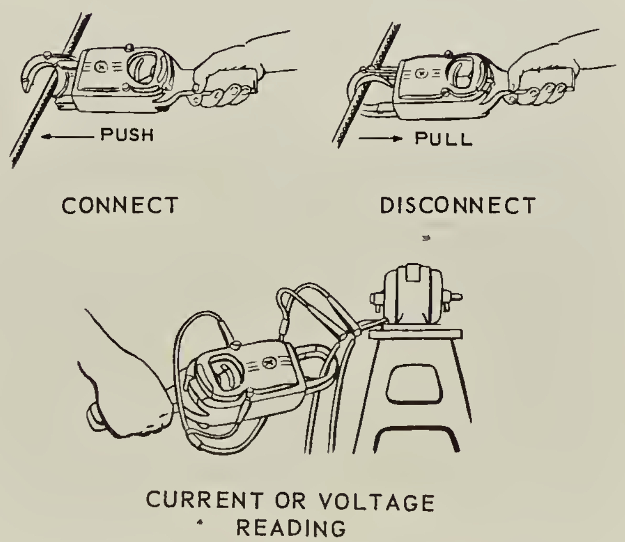


Figure 8-14. Using a clamp-on ammeter.

ment measures the current flow of a wire by making it serve as the primary of a transformer. The circuit to the meter movement acts as the secondary.

Always select a high scale when reading starting amperage, to protect the instrument from damage. When measuring the current load to a single-phase, 240-V, three-wire appliance, be careful to attach the instrument to one hot line and not to the neutral wire. To connect to the neutral would only indicate the current draw of the 120-V components.

A useful accessory for a tong ammeter which can extend the range of each meter scale is an adapter that can be plugged into the wall. The

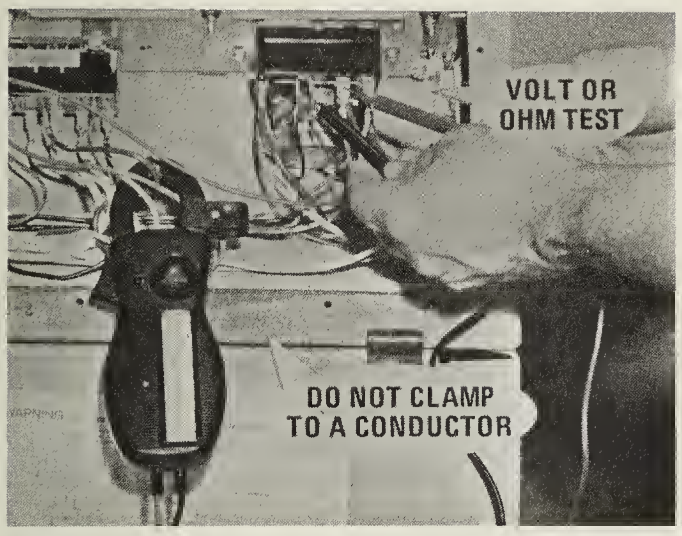


Figure 8-15. A clamp-on meter being used as a voltmeter or ohmmeter.

appliance is connected to the other end, and the jaws of the test instrument placed in one of the openings. The section marked " × 1" gives a direct scale reading, " × 5" gives 5 times the sensitivity, " × 10" gives 10 times the sensitivity of the scale being used on the meter. Wrapping the conductor wire around the jaws of the tong ammeter will give similar results. The sensitivity of the instrument will be multiplied by the number of turns taken.

Many tong ammeters are true multimeters. Test probes and direct-reading scales are provided for one or more voltage ranges. Some makes have external batteries and can be used as ohmmeters. When any tong meter is being used as a voltmeter or ohmmeter, the jaws should never be snapped around any object, particularly a current-carrying component or wire.

The current-measuring principle can be used on recording instruments like the one shown in Fig. 8-16. This device is recording the input voltage and current to an appliance on pressure-sensitive tape. Intermittent low-voltage conditions have become common in some areas of the country because of the extremely high demand for electric power. When voltage falls below 10 percent of the nameplate rating for an appliance, the appliance cannot be expected to function as designed. Verifying the true cause of low-voltage failures can be accomplished by the use of a recording volt/ammeter connected to either the service panel or the appliance. The recorder automatically logs voltage and/or current fluctuations on a lined tape or chart. Follow the manufacturer's instructions for connecting and adjusting this type of recording instrument.

Wattmeters. The applianee wattmeter can be used to read input voltage, which must be within

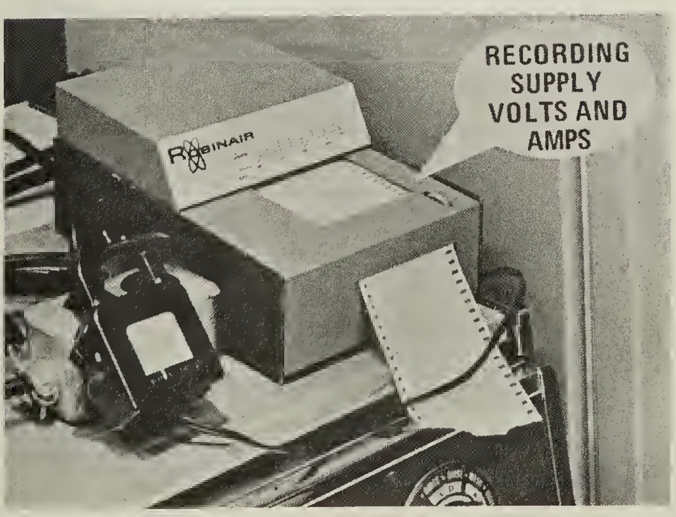


Figure 8-16. A typical current-measuring recorder device.

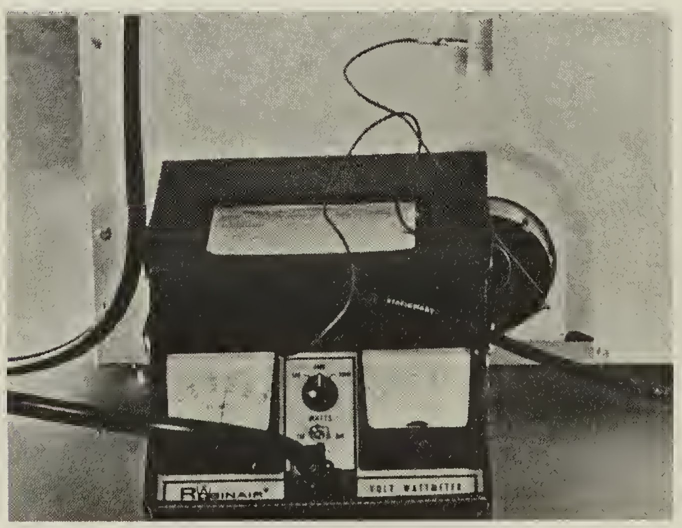


Figure 8-17. Appliance wattmeter in use.

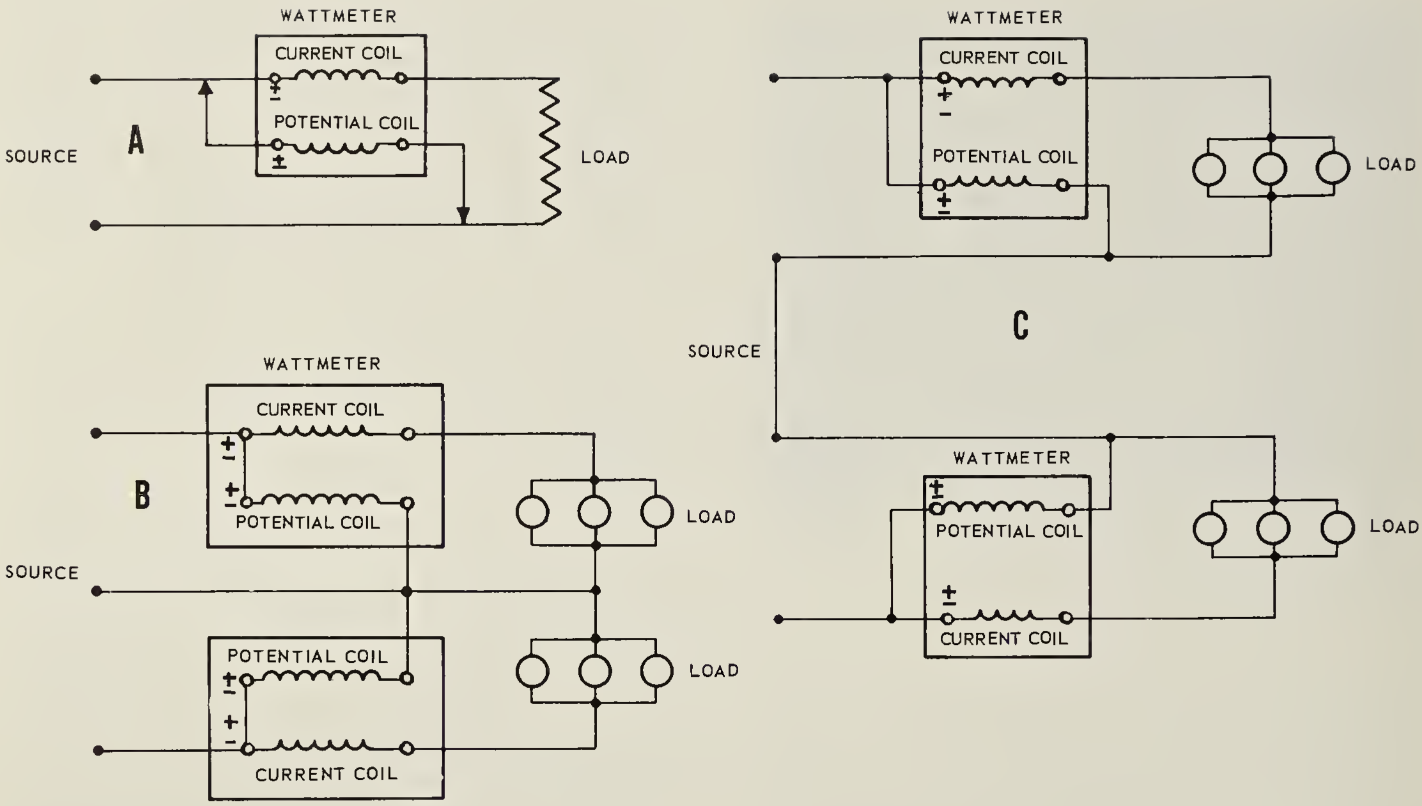


Figure 8-18. Wattmeter connected in various circuits.

10 percent of the nameplate voltage at the instant of start, as well as the *total* wattage draw of the energized appliance circuits. The wattmeter should not be confused with a watthour meter, which registers the total amount of energy consumed in a circuit.

A single-phase wattmeter contains two coils, one of which must be connected across the line to measure voltage, while the other one is connected in series with the load to measure current. (Most modern wattmeters use a tong-type ammeter to supply the current coil.) The moving coil is the voltage, or potential, coil, while the fixed coil is the current, or field, coil. The deflection of the wattmeter gives a direct reading in watts. But, as in all voltage-measuring instruments, start by using the highest scale first, then turn the selector until midscale readings are obtained. This prevents possible damage to the meter movement.

As mentioned, the wattmeter consists of two circuits, either of which will be damaged if too much current is passed through them. This fact is to be especially emphasized in the case of wattmeters, because the reading of the instrument does not serve to tell the user that the coils are being overheated. If an ammeter or voltmeter is overloaded, the pointer will be indicating beyond the upper limit of its scale. In the wattmeter, both the current and potential circuits may be carrying such an overload that their insulation is burning, and yet the pointer may be only part way up the scale. This is because the position of the pointer depends upon the power factor of the circuit as well as upon the voltage and current. Thus, a low-power-factor circuit will give a very low reading on the wattmeter even when the current and potential circuits are loaded to the maximum safe limit. This safe rating is generally given on the face of the instrument.

Capacitor analyzer. The capacitor analyzer is a very valuable tool. There are several varieties available; most are similar to the one illustrated in Fig. 8-19. This unit will test for open or

Figure 8-19. A typical capacitor analyzer.

shorted capacitors, for microfarad capacity, and for power factor. It will do this with accuracy, safety, and simplicity.

To give you some idea as to how a capacitor analyzer operates, we have selected a typical unit, which is illustrated in Fig. 8-19. While other models may vary slightly in operation, the same general information will apply. To operate an analyzer of this type, select the voltage that will be supplied to the instrument, plug in, and allow time to warm up. Select the test range to match the capacitor being tested. Connect the capacitor to the test leads. The illustrated unit is designed so that the capacitor is discharged whenever the spring-loaded test switch is at its rest position. Some instruments do not have this feature, and the charged capacitor must be discharged after each test with a 20,000-Ω resistor. Set the "power factor" indicator to zero. Set the test-scale knob to its full counterclockwise position. Hold the spring-loaded test switch to the TEST position and turn the test-scale knob until the dark portion of the test "eye" is at its widest point (Fig. 8-20). Then turn the power-factor knob clockwise until the edges of the dark eye are sharp and well defined. Most manufacturers' specifications will accept a starting capacitor with a power factor of 4 percent or less and a running capacitor with a power factor of 15 percent or less. The microfarad rating should be within 20 percent of specifications on a starting capacitor and 5 percent on a running capacitor.

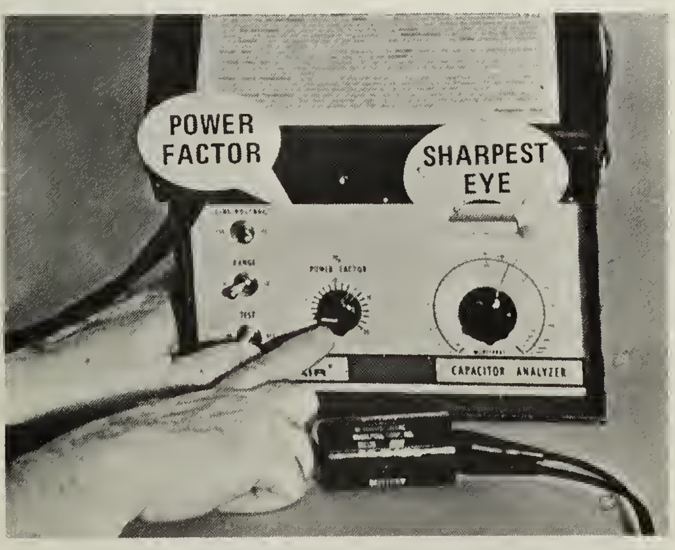


Figure 8-20. Checking the power factor with a capacitor analyzer.

Remember, when discharging capacitors so they are safe to handle, use a 20,000-Ω, 2-W resistor. Many expensive running capacitors are internally fused, and to discharge such a capacitor with a screwdriver can cause the fuse to blow and render the capacitor useless.

When reconnecting a running capacitor after testing, be sure that the marked terminal is on the supply-voltage side (not on the load side). This protects the starting windings from burnout should the capacitor develop a short circuit to its case.

Continuity testers. In addition to the ohmmeter method, which was described earlier in the

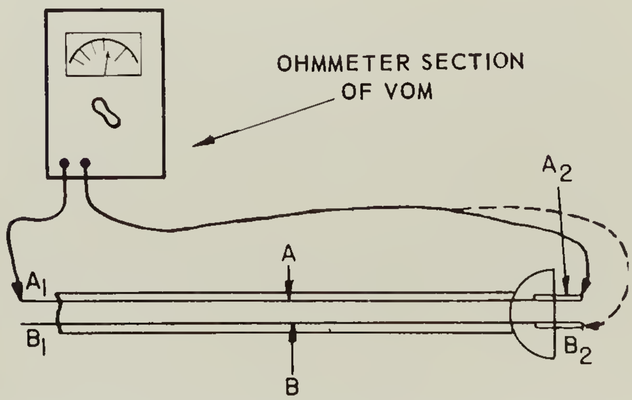


Figure 8-21. Using the ohmmeter to check a line cord.

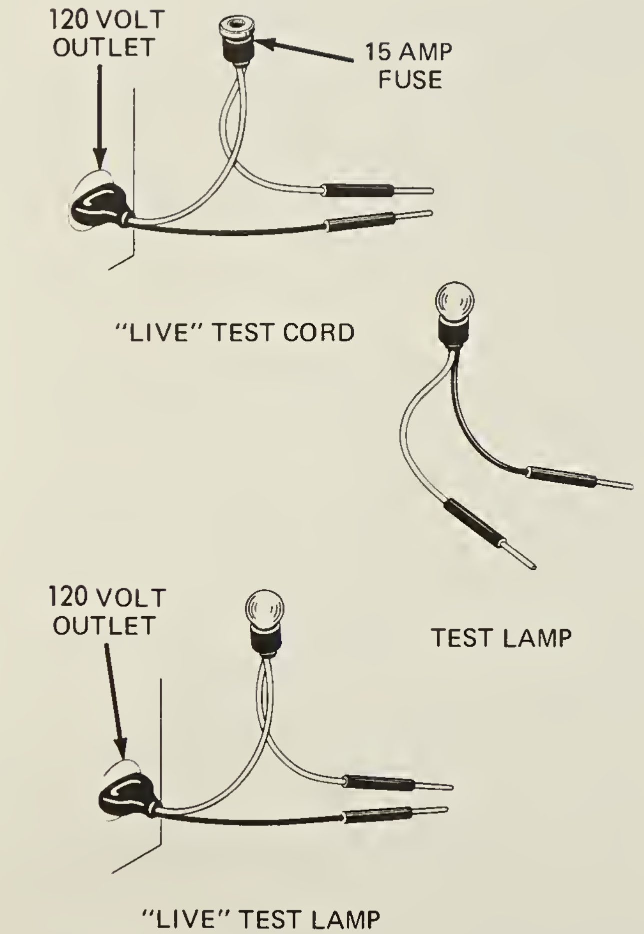


Figure 8-22. Three types of test cords and lamps.

chapter, there are three commonly used indicators of continuity. They are (1) an ordinary light bulb, (2) a neon lamp, and (3) a flashlight bulb.

A 25-W, 120-V bulb may be used as a test lamp to check 120-V current, while a 25-W, 240-V lamp should be employed when checking appliances which operate on a higher working voltage. (A 120-V bulb burns out very quickly on a 240-V circuit. But, it is rather difficult in some parts of our country to find a 240-V bulb; they must be purchased, as a rule, from electrical supply houses as a special order.) Use a keyless weatherproof socket of molded rubber construction with the leads permanently attached. To each of these permanent leads attach a piece of solid wire. That is, strip off the insulation from one end of each piece of solid wire for approximately an inch. Also strip the ends of the leads from the socket, splice them to the ends of the solid wires, and solder the joint. Then wrap plastic electrician's tape around the entire connection. Skin about $\frac{1}{2}$ in of insulation off the ends of both solid wires. The prods can be shaped to a point with a knife. You will have many uses for a test lamp, not only for testing supply circuits, but also for checking the wiring within an appliance under certain circumstances.

A pocket-type neon-lamp tester may perform most of the tasks that test lamps will do. It has the advantage of being more compact and the disadvantage of giving off a very small light which is not so easily seen.

The third continuity tester, which is very effective in tracing appliance circuits, can be made from two flashlight batteries, a flashlight bulb, and two lengths of ordinary insulated wire. Cut the wire into required lengths and solder the two battery terminals, the bulb, and two 3-ft lengths of wire in series. Bare about 1 in of the free ends of the long wires and tin them with solder to stiffen them. When these leads are touched together or on the ends of a continuous circuit the bulb will light.

Figure 8-23. A typical neon-lamp tester.

A variation of this continuity tester can be made by substituting a bell or buzzer for the flashlight bulb and using C batteries in place of flashlight batteries. Thus, when the prods (leads) are touched together or are connected to the ends of a continuous circuit, the bell or buzzer will

Figure 8-24. A continuity tester using a bell.

sound. Never use a battery type of tester or any ohmmeter on an appliance that is plugged in or connected to the power line, even if the appliance ON-OFF switch is off. Always disconnect the appliance before making any continuity test.

Series tester. The series test lamp uses household electricity instead of dry-cell batteries. To assemble this tester, connect the lamp socket, the prods, and the cord set in series. Thus, when the test prods are brought in contact with each other or are connected to the ends of a continuous circuit, and the tester is plugged into a wall outlet, the bulb will light. You can increase the usefulness of this device by making the prod leads disconnectable as shown here. This will enable you to connect an appliance cord to the tester, instead of the prod leads, when such a connecting scheme is desirable.

A series tester for a workshop bench is shown in Fig. 8-25. It is a simple continuity tester that also includes a 1,000-W screw-in heating element from a bowl-type heater (see Chap. 6, *Small Appliance Servicing Guide*). The element is connected in parallel with the 25-W lamp by closing the switch beside it. This adjunct enables you,

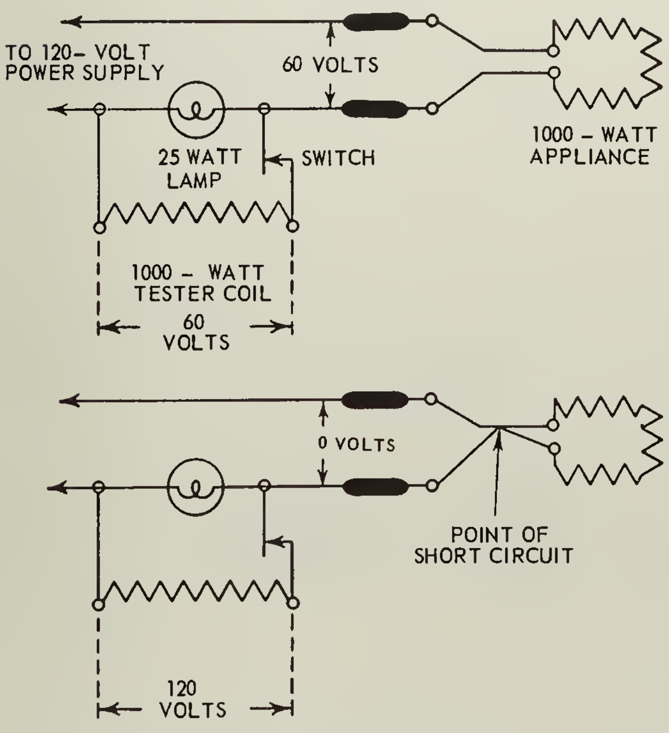


Figure 8-25. Bench-type series tester.

by flipping a switch, to distinguish between a short circuit and an unbroken normal circuit in an appliance under test, either of which would cause the series lamp to light.

In operation, when you first connect an appliance (rated at approximately 75 W or more) to the series tester, the lamp will appear to glow to almost its normal brilliance if there is a closed circuit in the appliance. Then, to determine whether or not the appliance is short-circuited, close the switch which connects the 1,000-W tester coil in parallel with the series lamp. If the lamp dims when the switch is closed, no short circuit is indicated; but if the lamp continues to burn as brightly as before, the appliance is short-circuited.

Short-circuiting loops are used frequently in conjunction with the series tester. For nearly every testing operation, two types of these loops will serve, one of which consists of a short length of flexible wire with an alligator clip attached to each end, and the other of several U-shaped pieces of solid copper or lead wire of assorted diameters so graded that each will fit snugly into the contacts of the terminal plug for which a particular loop is intended.

When conducting an operating test on many of the automatic small appliances, you must be able to tell when the power is turned on and shut off automatically. The power outlet with a pilot lamp is so designed that its lamp will glow only when current is being drawn from the outlet by an appliance rated at approximately 400 W or more.

High-potential (hi-pot) tester. The high-potential (hi-pot) tester is just a simple continuity tester that employs test voltages in the neighborhood of 1,000 to 1,500 V rather than the 120 V or less used with ones previously discussed. Its function is to locate potential points in the electric insulation which might permit circuit voltages to leak onto nonelectric metal areas of an appliance. While these high-voltage leaks usually do not affect the operation of the unit too greatly, they can be a serious shock hazard to the user.

To operate a typical hi-pot tester such as the

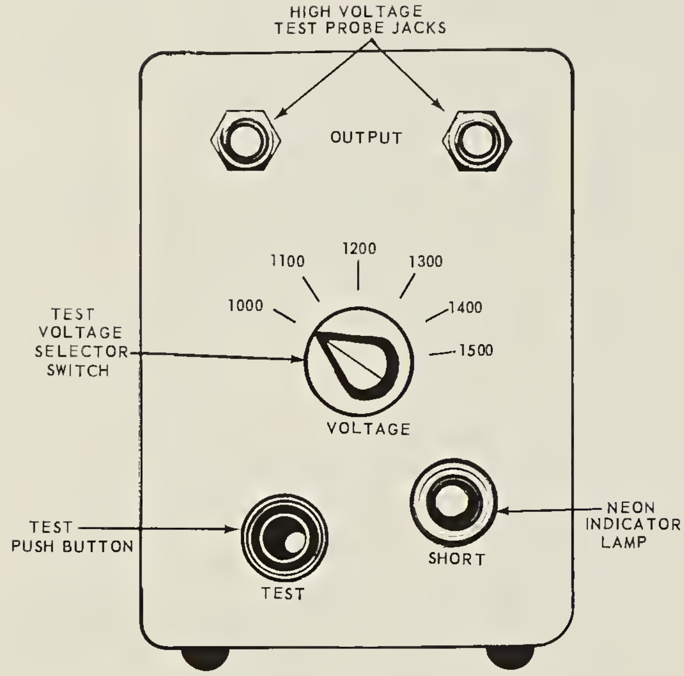


Figure 8-26. Basic hi-pot tester.

one shown in Fig. 8-26, one of the heavily insulated test probes should be connected to one of the "hot" prongs on the cord set of the appliance being tested. The other test probe is then connected to an exposed nonelectric portion of the appliance. The test-voltage selector switch is then set to the voltage recommended in the service manual. (While many manufacturers do recommend a hi-pot in the final testing of their appliances, others do not. For this reason, if there are no hi-pot test voltages given, do not give the appliance this test.) To make the test, depress the TEST push button for a short time interval, usually between a few seconds to one minute depending on the manufacturer's recommendation. If there are no high-voltage leaks in the appliance, the neon indicator lamp will not light or will burn very dimly. But if the high voltage breaks down any weak spots in the circuit insulation, the neon indicator lamp will burn brightly. Remember when testing motor-driven appliances to be sure to permit the motor to warm up sufficiently before making the test. A warm motor is more likely to show high-voltage breakdown than a cold one.

A great deal of caution should be practiced when using a hi-pot tester because of the high voltages employed.

Test cords. In addition to your standard test leads, which have the prods on one end and an attachment plug on the other, you will need to have several other test-cord sets for special applications such as connecting across the line for a preliminary operating test or to test an appliance whose cord set is not usable. These assemblies should be equipped with a variety of connectors and tips that will afford quick and easy temporary attachment to whatever types of appliances you service. To make up an initial assortment of test cords for general use, seven types of terminals usually will suffice. They are (1) the standard heater plug, as used on most detachable iron cords; (2) the small heater plug, commonly used on many coffee-making appliance cords; (3) the roaster plug, which is somewhat larger than the standard iron plug; (4) straight wire tips (tinned); (5) eyelets; (6) compression sleeves, which are nothing more than the contacts from a standard heater plug; and

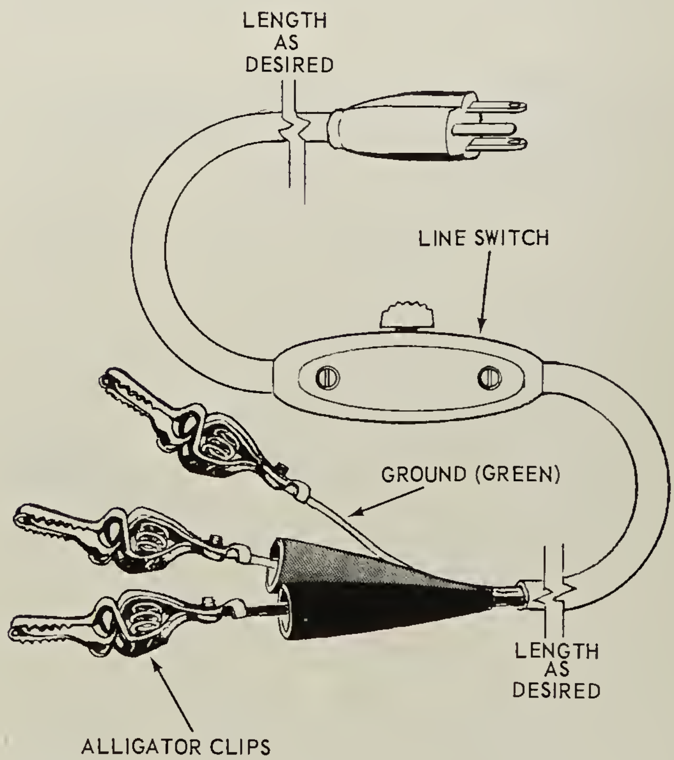


Figure 8-27. A typical test cord used for servicing major appliances.

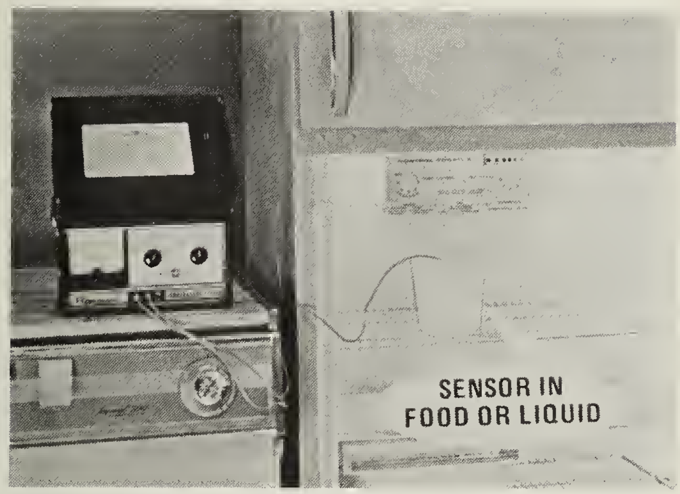


Figure 8-28. An electronic temperature tester.

(7) alligator clips. It should go without saying that the other end of each cord is to be fitted with a standard attachment plug.

There are special pieces of test equipment and tools needed to service specific appliances. For instance, an electronic temperature tester (Fig. 8-28) is sometimes needed to check the coolness or the operation of a refrigerator. (See Chap. 1 of *Refrigeration, Air Conditioning, Range and Oven Servicing.*) In other words, any special test equipment or tools required to service an appliance will be covered in the chapter and book dealing with the particular appliance.

TOOLS

Having the proper tool available when repairing an appliance is most important. Not only does it make the job a great deal easier, but it helps to prevent damage to appliance parts.

When equipping your shop and tool kit, be sure to obtain good tools. Avoid cheap tools. Remember that, when used properly, good tools will last a very long time and are therefore an investment.

Pliers

Basically, pliers were designed to hold materials with firmer pressure than mere fingers can give. But they can also cut, squeeze, clamp, pick up, pull, bend and turn. While most plier types are versatile, there is no such thing as a single pair of pliers that performs all the tasks of its cousins. To illustrate this point, consider that there are 125 standard types and sizes of pliers made by one manufacturer alone. The pliers that we shall describe here are the ones most valuable to the service technician.

Diagonal side-cutters. Often called "dikes," this type of pliers has but one function—cutting. The jaws, being on a diagonal to the handles (about 15°), are suited to cutting small objects flush with a surface, and the slightly curved contour of the cutting face permits better-than-average leverage. They will cut medium-gauge electrical wire, both metal and plastic, and a wide variety of small nails and pins. Heavy-duty diagonal pliers can remove cotter keys faster than any other tool; simply sever the spread ends of the key, grip the head, and pry the key out with a sideways motion.

Stripping insulation from an electrical wire is another easy job for diagonal cutters. After cutting through the insulation, the plier handles are rocked back and forth, the prying action separating the insulation from the wire, allowing you to strip the wire clean.

Although diagonal side-cutters are available in a variety of sizes, the 5-to-6-in size is the most useful for the service technician. It is large enough to cut medium-gauge wires, metals, and plastics with comparative ease, yet it is small enough for the demands of working in tight spots. Do not, however, use diagonal-cutting pliers to cut heavy-gauge wire. Overloading the cutting edges can spring the jaws so that cutting edges do not meet evenly, making precise cuts impossible on smaller wires.

Side-cutting pliers. Larger and huskier than diagonal-cutting pliers, electrician's side-cutting pliers are designed for big jobs—cutting heavy-gauge wire, medium-sized nails, and extra-large keys. Square-nosed and having serrated tips, side-cutters will hold large and small pieces of flat metal with ease, for bending, cutting, and drilling jobs. They can easily handle heavy-appliance

projects that require cutting 12-gauge or larger wire.

The handles of some side-cutting pliers—as well as other types—are covered with plastic, but this is not necessarily an insulating material. Therefore, before doing any work where insulation would be important, make sure the pliers' covering really insulates. It is usually identified right on the material—or fabricate your own protection from lengths of rubber tubing slipped over the handles.

Long-nosed pliers. Long-nosed pliers, sometimes called needle-nose pliers, are extremely valuable to the technician as an extension of the fingers. Inserting, spreading, and twisting cotter pins, forming eyes on wires for electric connections, and manipulating parts too small to be held by hand are some of the many practical uses.

Due to a traditional spread-handle design and a long, thin gripping surface which is scored at the tips, these pliers provide extraordinary control of thin and otherwise hard-to-grip objects, and are exceptionally useful for working in a small space. They are particularly useful for holding small wires during soldering operations. When preparing eyes or loops on the ends of wires, simply grasp the end with the tip of the pliers and twist the wrist for perfect results.

The long-nosed pliers come in many variations. There are, for example, various jaw types, lengths, thicknesses and tapers. Some have partially milled jaws, others are smooth. There are "duckbill" types for handling delicate flat objects, angled jaws for reaching around obstructions, round noses for bending smooth curves in wire, and many more.

Stripping and crimping pliers. For many appliance jobs, a pair of combination wire-stripping and crimping pliers do a quick, neat job of preparing a wire and attaching a lug to it. The lug is then slipped under the screw terminal to make a perfect, tight connection. The jaws of these pliers also have cutting edges.

Slip-joint pliers. Slip-joint pliers get their name from their main and most obvious feature, a pivot pin that allows the jaws to slip open for gripping wider workpieces. They can serve as a pipe vise, and with their jaws taped they can be used to hold all kinds of delicate items.

The best combination slip-joint pliers have fine serrations on the inside tips of the jaws for gripping small objects like wire, and coarser teeth further back for holding larger objects like pipes and rods.

While closely related, the multiple-slip-joint or utility pliers have two main differences. The jaws are at a right angle to the handles, and the pivot, instead of having only two possible positions, may have as many as ten. The handles are close together and easy to grip, so you can exert force with them comparable to what you can do with a wrench of equal length. Multiple-slip-joint pliers come in many sizes, from a few inches long to huge ones whose jaws open to six inches or more. The 10- or 12-in size is the most useful for the service technician.

Vise-grip pliers are also very valuable to the service technician. They can be used as a powerful clamp or a wrench with a strong bite. The screw on the handle adjusts the jaws to the work; squeeze the handles and the jaws lock on it.

Care in purchasing and maintenance. When purchasing a tool, look for a pliers with finely machined jaws and cutting edges that are precisely aligned. If you are looking at slip-joint pliers, test the action of the pivot bolt to be sure it does not slip.

All it takes is a drop of oil now and then to keep moving parts free. A thorough cleaning of the pliers' serrations with a wire brush or a three-cornered file assures a good, clean bite.

Screwdrivers

There is no such thing as an all-purpose screwdriver—the screwdriver must be suited to the job. For this reason, a service technician must have several different types available. In all cases, remember that the tip of the screwdriver *must* fit the screw slot. If the blade tip is too wide, it may ruin the wood around the head of the screw. If the tip is too narrow, chances are it will slip and chew up the head of the screw.

Conventional screwdrivers. Conventional or common screwdrivers are classified by shaft

length (not total length) and tip width, with dimensions usually proportionate. Shaft sizes range from $1\frac{1}{2}$ to 20 in with tips correspondingly smaller or larger. But, if you had to, you could get one with disproportionate dimensions, say a long shaft and narrow tip, such as is needed for some appliance work. The great majority of common screwdrivers have round shafts, but you can get a square variety, handy for grabbing with a wrench when you need extra torque to loosen a rusted-on or frozen screw.

Screwdrivers are made with handles of many different materials. Most service technicians prefer the plastic ones because they are comfortable, durable, and shockproof.

For the many straight-slot screws used in appliances—and in keeping with what we said about matching screwdriver size to screw size—a minimum assortment would be the following: a $\frac{7}{32}$-in tip with a 3-in shaft; a $\frac{1}{4}$-in tip with a 4-in shaft; a $\frac{5}{16}$-in tip with a 6-in shaft; a $\frac{3}{8}$-in tip with an 8-in shaft; and a $\frac{3}{8}$-in tip with a 10-in shaft. And, for getting into especially tight places, you should have a stubby $1\frac{1}{2}$-in screwdriver with a $\frac{1}{4}$-in tip.

Phillips screwdrivers. Many appliance manufacturers seem to prefer the Phillips type of screw. In this screw, the heads are formed with two slots at right angles to each other and with slightly rounded bottoms, and they therefore require special screwdrivers with tips of mating shape. Why do manufacturers prefer this kind over the conventional type? Because the Phillips head lends itself better to fast assembly with air- or motor-driven tools. That is, the driving bit centers itself almost automatically in the opening in the screw head, and once it is in it does not slip out.

Phillips screwdrivers are numbered No. 0, No. 1, No. 2, No. 3, and No. 4 according to tip size, or, as it is technically known, point size. For service work, a No. 1 and a No. 3 with 3- and 6-in blades, respectively, will handle most jobs. You may also want to get a short 1- or $1\frac{1}{2}$-in Phillips with a No. 2 or No. 3 point, because Phillips screws can be in hard-to-get-at places also.

Offset screwdrivers. Offset screwdrivers are used where there is not sufficient space to employ the common screwdriver. The offset type has two blades at opposite ends, made at right angles to one another, and the tool is made of round or octagonal steel. When working in almost inaccessible places, it may be necessary to use both ends, first one for a short distance, then the other blade.

Spring-jaw holders for screwdrivers. One of the most useful gadgets are "screw-holding" screwdrivers. They leave one hand free to hold the object in place while you are attempting to get a screw started, and they are great temper savers.

There are two basic types of spring-jaw holders. One has a split blade which spreads apart as you slide a collar down the shaft. As the blade spreads, it gets thicker; as it does, it squeezes against the sides of the screw slot, holding it firmly. The second type has two little spring clamps which also slide up and down the shaft. The clamps hold the screw in place until it bites into the hole. Most service technicians prefer the split-blade type when using a brand-new screw, but the spring clamps work better if you have to make do with an old screw, whose slot may be somewhat chewed up. Most often, the screw-holders are for flat-blade screwdrivers, but there are some made for Phillips screwdrivers also.

Care in purchasing and maintenance. Whatever screwdriver you purchase, make sure it is of good quality. Poor tools are a bad investment. The tips of cheap screwdrivers are badly ground and are of low-grade steel. They will soon round off or bend and become practically useless.

Even the finest of screwdrivers eventually wears and becomes rounded. But, it is easy to regrind the tip with an emery wheel or file.

Nut Drivers and Wrenches

The so-called "nut drivers" have the handle and the shaft of a screwdriver and the end of a socket. That is, the shaft is hollow for about half its length, so it can be slipped over the

end of a long screw to reach a nut on it. An extension handle is available which helps to get down into narrow places. The extension handle also gives a little better grip to the nut driver for breaking stubborn nuts loose. In addition, these tools are useful in handling hexagonal-head screws. It is advisable for the service technician to have a complete set of nut drivers available.

As to wrenches for larger nuts and bolts, the service technician has a wide selection to choose from. Here are the ones you should consider.

Open-end wrenches. Open-end wrenches are one-piece tools with a nonadjustable, elongated half-moon-type opening at one or both ends. (The vast majority have different openings at each end. A $\frac{1}{2} \times \frac{9}{16}$ in wrench, for example, has an opening to fit $\frac{1}{2}$-in-diameter nuts on one end and $\frac{9}{16}$-in nuts on the other.) The lengths of the wrench handles are proportionate to the sizes of the openings—the larger the opening, the longer the handle. This increases the leverage, and reduces the possibility of the technician applying too great a force on the nut, which might either strip the threads or twist the bolt until it breaks. The ideal tool kit contains wrenches with openings ranging from $\frac{5}{16}$ to 1 in in width.

Box wrenches. Box wrenches are so named because they completely surround or "box" the nut or bolt head. Some such wrenches have six notches within the box, but most have 12 notches or "points" to grasp the nut. With a 12-point box wrench, you can loosen a nut in a tight area where you can swing the wrench just 15° (admittedly a tiresome job) compared to the 60° required for a normal open-end wrench (or 30° with "flopping").

Because of its ability to perform in such limited areas, the box wrench is a favorite with service technicians when working in close quarters. Another reason for its popularity is that it is practically impossible for a box wrench to slip off the nut. Still another advantage scored for the box wrench is that its head is narrower, and it can often get at nuts that are hard or impossible to fit with an open-end wrench. And unlike open-end wrenches, box wrenches may be offset, allowing them to reach nuts that may otherwise be inaccessible.

Box-wrench sizes are similar to those of open-end wrenches. Generally, one end of the wrench differs from the other by $\frac{1}{16}$ in, although some sets come in gradations of $\frac{1}{32}$ in or $\frac{1}{8}$ in.

Combination wrenches. The combination wrench is just that, with one end an open end and the other a box. Both are of the same size, so it is possible to use the box for breaking loose a stubborn nut, then continue the loosening with the open end. The reverse also applies, of course—the nut is tightened most of the way with the open end, then "snugged down" with the box end.

Adjustable wrenches. The adjustable, or crescent, wrench's big advantage is that it can be used on any size nut within the capacity of its jaws—there is no need to experiment with different-sized tools. Simply turn the knurled nut on the wrench head and the wrench adjusts to fit.

This type of wrench is available in a broad range of sizes, determined by the length of the handle—jaw openings are proportionately larger in the larger sizes. Many manufacturers offer locking adjustables; when the jaws have been adjusted for proper fit, they can be locked in that position so that they will not enlarge or slip off the work.

Socket wrenches. A set of socket wrenches contains a range of sizes of detachable sockets, along with a number of different types of handles to suit various needs. The sockets have either six or twelve points on the front, to grasp the nut, and they have a square hole at the back. The hole may be $\frac{1}{4}$-, $\frac{3}{8}$-, or $\frac{1}{2}$-in square. The various handles all have a protruding square stud that fits the hole at the back of the socket. The stud is called a *drive*, and a set of sockets with holes that fit a $\frac{3}{8}$-in stud are known as $\frac{3}{8}$ *drive*. In addition to the standard sockets, there are deep sockets (for such uses as getting at nuts set well down onto protruding bolts) and flex sockets (which are hinged to allow working at various angles).

While there are various useful handles, probably the most versatile handle is the ratchet. Inserted into the socket, it will speedily remove or tighten any nut with a relative minimum of swing room. Most ratchet handles can be adjusted to work in either direction.

Setscrew wrenches. These are the familiar Allen wrenches, also called hex wrenches because of their hexagonal shape. They are inserted into the head of a setscrew to turn it in or out. They may be simply individual L-shaped bars of tool steel or they may come in sets of different sizes, either on a ring or folding out of a case. The setscrew wrench is a very simple tool, but when you need one, there is no substitute. They are inexpensive, and a set of various sizes should be in every technician's service kit.

Soldering Tools

Soldering is a very important process (see p. 169) in all electrical work, because loose or broken wires in appliances of all kinds are very common. Here are the tools used for soldering.

Soldering irons. All high-quality soldering irons operate in the temperature range of 500 to 600°F. Even the little 25-W "midget" irons produce this temperature. The important difference in iron sizes is not temperature, but thermal inertia (the capacity of the iron to generate and maintain a satisfactory soldering temperature while giving up heat to the joint to be soldered). Although it is not practical to try to solder a heavy metal box with a 25-W iron, that iron is quite suitable for replacing a $\frac{1}{2}$-W resistor in a printed circuit. An iron with a rating as large as 150 W would be satisfactory for use on a printed circuit, provided that suitable soldering techniques are used. One advantage of using a small iron for small work is that it is light and easy to handle, and it has a small tip which is easily inserted into close places. Also, even though its temperature is high, it does not have the capacity to transfer large quantities of heat.

Some irons have built-in thermostats. Others are provided with thermostatically controlled stands. These devices control the temperature of the soldering iron, but they are a source of trouble. A well-designed iron is self-regulating by virtue of the fact that the resistance of its element increases with rising temperature, thus limiting the flow of current. For critical work, it is convenient to have a variable transformer for fine adjustment of heat; but for general-purpose work, no temperature regulation is needed.

Figure 8-29. A typical soldering gun.

Soldering gun. The soldering gun (Fig. 8-29) has gained great popularity in recent years because it heats and cools rapidly. It is especially well adapted to maintenance and troubleshooting work, where only a small part of the service technician's time is spent actually soldering. A soldering iron, if kept hot constantly, oxidizes rapidly and is therefore difficult to keep clean.

A transformer in the soldering gun supplies approximately 1 V at high current to a loop of copper which acts as the tip. It heats to soldering temperature in 3 to 5 s, but may overheat to the point of incandescence if left on over 30 s. The gun is operated with a finger switch so that the gun heats only while the switch is depressed. Since the gun normally operates only for short periods at a time, it is comparatively easy to keep clean and well tinned; i.e., little oxidation is allowed to form. However, the tip is made of pure copper, and is susceptible to the pitting which results from the dissolving action of the solder.

Tinning of the tip is always desirable, unless it has already been done. The gun or iron should always be kept tinned in order to permit proper heat transfer to the work to be soldered. Tinning also provides adequate control of the heat to prevent thermal spillover to nearby materials. Tinning of the tip of a gun may be somewhat more difficult than tinning the tip of an iron. Maintaining the proper tinning on either type, however, may be made easier by tinning with silver solder. The temperature at which the bond is formed between the copper tip and the silver solder is considerably higher than with lead-tin solder. This tends to decrease the pitting action of the solder on the copper tip.

Pitting of the tip indicates the need for retinning, after first filing away a portion of the tip. Retinning too often results in using up the tip too fast.

Overheating can easily occur when using the gun to solder delicate wiring. With practice, however, the heat can be accurately controlled by pulsing the gun on and off with its trigger. For most jobs, even the LOW position of the trigger overheats the soldering gun after 10 s; the HIGH position is used only for fast heating and for soldering heavy connections.

Heating and cooling cycles tend to loosen the nuts or screws which retain the replaceable tips on the soldering irons or guns. When the nut on a gun is loosened, the resistance of the tip connection increases, and the temperature of the connection is increased. Continued loosening may eventually cause an open circuit. Therefore, the nut should be tightened periodically.

Resistance soldering. A time-controlled resistance soldering set is now available. The set consists of a transformer that supplies 3 or 6 V at high current to stainless steel or carbon tips. The transformer is turned on by a foot switch and off by an electronic timer. The timer can be adjusted for as long as 3 s of soldering time. This set is especially useful for soldering cables to plugs and similar connectors—even the smallest types available.

In use, the double-tip probes of the soldering unit are adjusted to straddle the connector cup to be soldered. One pulse of current heats it for tinning, and, after the wire is inserted, a second pulse of current completes the job. Since the soldering tips are hot only during the brief period of actual soldering, burning of wire insulation and melting of connector inserts are greatly minimized.

The greatest difficulty with this device is keeping the probe tips free of rosin and corrosion. A cleaning block is mounted on the transformer case for this purpose. Some technicians prefer fine sandpaper for cleaning the double tips. *Caution*: Do not use steel wool. It is dangerous when used around electrical equipment.

Pencil iron and special tips. An almost indispensable item is the pencil-type soldering iron with an assortment of tips. Miniature soldering irons, with wattage ratings of less than 40 W, are easy to use and are recommended for many applications. In an emergency, larger irons can be converted and used on subminiature equipment.

One type of iron (Fig. 8-30) is equipped with several different tips that range from $\frac{1}{4}$ to $\frac{1}{2}$ in in size (diameter) and are of various shapes. This feature makes the iron adaptable to a variety of jobs. Unlike most tips, which are held in place by setscrews, these tips have threads

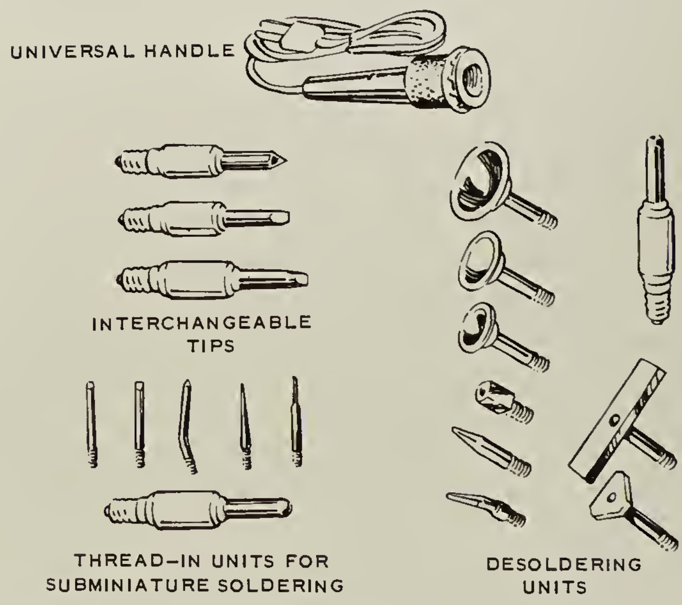


Figure 8-30. Pencil iron kit with special tips.

and screw into the barrel. This feature provides excellent contact with the heating element, thus improving heat transfer efficiency. A pad of "antiseize" compound is supplied with each iron. This compound is applied to the threads each time a tip is installed in the iron, thereby enabling the tip to be easily removed when another is to be inserted. A special feature of this iron is the soldering pot that screws in like a tip and holds about a thimbleful of solder. It is useful for tinning the ends of large numbers of wires.

The interchangeable tips are of various sizes and shapes for specific applications. Extra tips may be obtained and shaped to serve special purposes. The thread-in units are useful in soldering subminiature items. The desoldering units are specifically designed for performing special and individual functions.

Another advantage of the pencil soldering iron is its possible use as an improvised light source for inspections. Simply remove the soldering tip and insert a 120-V, 6-W, type 6S6, candelabra-screwbase lamp bulb into the socket. If leads, tabs, or small wires are bent against a board or terminal, slotted tips may be used to simultaneously melt the solder and straighten the leads. A hollow tip, which fits over a pin terminal, may be used to desolder and resolder wiring at cables or feed-through terminals.

Many miniature components have multiple connections, all of which must be desoldered to permit removal of the component in one operation. These connections may be desoldered individually by heating each connection and brushing away the solder. With this method, particular care must be taken to insure that loose solder does not stick to other parts or become lodged where it may cause a short circuit. A more efficient method is to use the specially shaped desoldering units. Select the proper size and shape tip that will contact all terminals to be desoldered—and nothing else. Do not permit the tip to remain in contact with the terminals too long at one time.

If no suitable tip is available for a particular operation, an improvised tip may be made (Fig. 8-31). Wrap a length of copper wire around one of the regular tips, and bend the wire into the proper shape for the purpose. This method also serves to reduce tip temperature when a larger iron must be used on miniature components. Equipment needed for silver soldering is described in *Refrigeration, Air Conditioning, Range and Oven Servicing.*

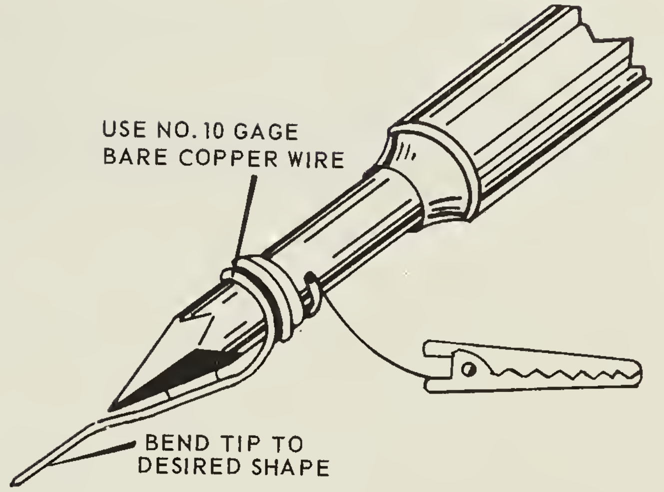


Figure 8-31. Improvised tip to reduce tip temperature.

Miscellaneous General Tools

Here is a list of general tools, in addition to those already mentioned, that should be available to technicians either in service kits or at the work bench:

Machinist's ball-peen hammer	Fuse puller
Scissors	Electrician's knife
Extension light	Hacksaw
Flashlight	Extension cord
Tooth brush	Set of punches
Dentist's mirror	C-ring tool
Flat mill file (medium)	Ice pick
Round file (medium)	Hand or power drill with set of drills
Tweezers (two different sizes)	Snap-ring pliers
	First-aid kit

Your service kit should also contain cans of cleaner, solvent, and lubricant. There are so-called special tools that are needed to service

specific appliances. In most cases these tools are designed by the manufacturer to do a special job on their appliances. Such tools are usually described in the service manual and are available directly from the manufacturer. While you can generally make the repair without use of special tools, they do make the job easier and quicker. Remember, when servicing appliances, time is money. Therefore, any tool that will save you time is valuable.

The service technician

CHAPTER

9

The home appliances which are commonplace today were luxuries 15 years ago. The number in use will increase rapidly during the next few years, reflecting the expanding population, consumer prosperity, and demand for more labor-saving devices. This tremendous growth in the use of home appliances will require more and more service technicians.

What does a service technician do? According to the official job description listed by the United States Department of Labor, an electrical appliance technician does the following:

> Services and repairs major electrical appliances (and the electrical components of gas-operated appliances) such as ranges, refrigerators, freezers, dishwashing machines, disposers, washers, dryers, and window air conditioners, and small household appliances such as food mixers, toasters, irons, fans and vacuum cleaners. (As a general rule, the distinction between major and small household appliances is that the former require installation while the latter do not.) Work includes most of the following: Checks operation of appliance by sight and sound, using test meters to locate and isolate trouble area; as required disassembles appliance and examines mechanical and electrical parts; traces electrical circuits, following diagram, and locates trouble; cleans and washes parts; replaces worn or defective parts; repairs and adjusts appliance motors; reassembles appliance; and lubricates moving parts. May install appliances and test for satisfactory operations. Does *not* include repair of central air conditioning units or repair of radios or television sets.

The three other volumes in this series cover completely the servicing of small and major appliances, as well as putting the theory given in this book to practical use. But for now, let us take a look at the appliance servicing business.

WHERE ARE APPLIANCE SERVICE TECHNICIANS EMPLOYED?

Appliance service technicians are employed by small shops, large service companies, retail stores, and appliance manufacturers and distributors. Service personnel are employed in nearly every community in the country; however, the variety and extent of opportunity depends upon the population of the community.

Of the estimated 240,000 technicians employed throughout the country, more than half are employed by independent service agencies. About one-fourth of all appliance service technicians are employed in service centers or retail establishments, including department and appliance stores. The remainder are employed by manufacturers, by wholesale distributors of appliances, and by gas and electric utility companies. Because of the large number of small organizations among independent service agencies, many technicians are self-employed.

It is difficult to state a nationwide wage scale for appliance service personnel, because salaries vary according to the experience and competence of the technician, the size and type of the employer's establishment, the type of equipment serviced, and the geographical area. But, it is safe to say that the position of appliance technician is on one of the higher rungs of the entire servicing business' wage ladder. There is, however, so much more to a paycheck than what people call "take-home pay." A variety of fringe benefits, considered to be dollars in the pocket, increase this income and contribute to immediate, as well as long-range, security. Many appliance service technicians receive paid vacations, sick leave, health insurance, possible credit toward retirement pensions, and other employee benefits. In some instances, a higher base salary may be offered in lieu of providing costly employee benefit programs.

Inexperienced persons with basic electrical and mechanical abilities and an understanding of appliance equipment may obtain on-the-job apprentice training with local, independent service shops. Skill is acquired by working in the repair shop and/or by accompanying and assisting experienced service technicians on assignments in the field. Unskilled workers who demonstrate potential will also find opportunities with appliance manufacturers, some of which maintain technical training programs for their employees and for training candidates sponsored by local dealers who represent the manufacturer. Industry programs offer excellent in-depth training and the chance to specialize in servicing a specific product line.

The initial training period, generally 6 to 12 months, regardless of the training establishment, is usually balanced between practical "hands-on" experience and some form of classroom instruction. Trainees, particularly with local, independent shops, often supplement their training by taking correspondence courses in basic electricity or electronics, or by attending area technical schools on a part-time basis.

Appliance service technicians may require up to three years of on-the-job training to become fully qualified, but training does not end there. As in other professions, experienced technicians must continually sharpen their skills and keep abreast of the development of new appliances and service techniques. Appliance manufacturers offer assistance by conducting frequent workshop sessions throughout the United States and by furnishing current factory service manuals for study.

The experienced appliance service technician who is proficient in his work, responsible, motivated, and willing and able to deal well with people will find opportunities for advancement to foreman, to service manager, or to establishing his own service business. Similarly, service technicians who are employed by appliance manufacturers may aspire to positions such as instructors, technical writers, field service representatives, or service managers.

OWNING AN APPLIANCE SERVICING BUSINESS

Owning a business is the ultimate of most service technicians. However, considerable thought and research must be done in this area before you embark on such a venture. There are fundamentals to be considered before becoming too involved.

Before reaching a decision to open an appliance servicing shop, you would do well to evaluate your reasons for going into this business. Roughly, there are three basic motives and goals. You may be justified in entering this business if you fit into any of the three following categories.

1. Some people have gone into this business to provide themselves with jobs. These small owner-managers cannot find satisfactory jobs working for others in the areas where they wish to live, because they are too old or because they lack the required technical knowledge. They regard themselves as successful as long as their shops provide the living expenses they need.
2. A second group are in this business because they have a predetermined standard of living, and count on appliance servicing to earn enough money to maintain this standard. These people count themselves successful so long as they can achieve this objective.
3. Owner-managers in the third group are seeking an adequate return on both their time and their money. The truly successful appliance shop owners are in this group. They are very businesslike and expect an adequate return from every dollar invested. They try to keep every dollar working. They also place a value on their own time, based on what they believe they could be earning in other jobs or occupations. And they aim to pay themselves an adequate salary to cover their time.

Even though you may fit into one of the three categories, you perhaps have asked yourself: Am I the type to be successful as an owner-manager of an appliance service shop? There is no satisfactory self-analysis sheet for this business to give you a certain answer to this question. However, probably the best way to find the answer is to gain practical experience for yourself by working in an appliance service shop. Of course, if you are starting from scratch in such a job, with no previous appliance servicing experience, you are bound to make some mistakes. But the mistakes will be at someone else's expense. You may be champing at the bit, and eager to get rolling with your own business. But try to be patient. A few months or even a few years of working for someone

Rating Scale for Evaluating Personal Traits

Instructions: Place a check mark on the line following each trait where you think the mark ought to be. The check mark need not be placed directly under one of the guide phrases, because the rating may lie somewhere between the phrases.

Initiative	Additional tasks sought; highly ingenious	Resourceful; alert to opportunities	Regular work performed without waiting for directions	Routine worker awaiting directions
Attitude toward others	Positive; friendly interest in people	Pleasant, polite	Sometimes difficult to work with	Inclined to be quarrelsome or uncooperative
Leadership	Forceful, inspiring confidence and loyalty	Order giver	Driver	Weak
Responsibility	Responsibility sought and welcomed	Accepted without protest	Unwilling to assume without protest	Avoided whenever possible
Organizing ability	Highly capable of perceiving and arranging fundamentals in logical order	Able organizer	Fairly capable of organizing	Poor organizer
Industry	Industrious; capable of working hard for long hours	Can work hard, but not for too long a period	Fairly industrious	Hard work avoided
Decision	Quick and accurate	Good and careful	Quick, but often unsound	Hesitant and fearful
Sincerity	Courageous, square shooter	On the level	Fairly sincere	Inclined to lack sincerity
Perseverance	Highly steadfast in purpose; not discouraged by obstacles	Effort steadily maintained	Average determination and persistence	Little or no persistence
Physical energy	Highly energetic at all times	Energetic most of the time	Fairly energetic	Below average

else and observing his correct practices and his mistakes should be of immense value to you. It will also help you decide whether or not to go into business at all.

You must take full stock of yourself. What kind of leader are you? Are you willing to take calculated risks—"run for luck?" Can you "plan your work" and "work your plan?" Can you be firm with people—to the point of firing poor performers?

A short questionnaire is given on page 174, which will quickly determine whether you have these special qualities. It is a rating scale devised by the Small Business Administration for an evaluation of your personal traits in this area, and its ten points cover the range of abilities important to success in the management of one's own business concern. In filling it out, think about your answers carefully and be honest with yourself. You should remember that in establishing your own firm you will be risking your time and money as well as those of customers and creditors.

Management—that is, poor management—is the greatest single cause of failure in retailing, according to experts who have made studies of business success and failure. There are various definitions of management, but regardless of how you define it, management—good or bad—certainly involves the handling of hundreds of little details. It involves making dozens of decisions every day—decisions regarding parts, money, and men.

No matter how intelligent and capable you are, as a manager you are bound to overlook some details that will turn out to be important. You are also bound to make some wrong decisions—everyone does. But remember that the cause of failure is rarely the making of one wrong decision. The real threat to a business occurs when management postpones or refuses to make decisions.

Funding

The most important item besides hard work is capital. How much money will you need to open an appliance service shop? You will certainly face this question early in your planning. The general answer is that you will need enough to compete with other service shops in your area. However, since competition and marketing conditions vary from one location to another, there is no absolutely definite answer to the question of how much money you will need.

Obviously, the more money you have, the greater will be your chance of success. If you have adequate funds, you will be able to take advantage of various opportunities to expand and promote your business—the kind of opportunities that turn up sometimes but cost money to carry out. You will be able to avoid paying interest on loans that you would have to negotiate if your funds were inadequate. Adequate funds also would help you to survive errors in judgment you are almost sure to make in the early stages of your new venture. Yes, it is fine to have financial resources that are entirely adequate. But very few businessmen are in this enviable position. Almost every small retailer is faced, at one time or another, with the question you will face when you start your business, unless you are wealthy. This question is, How much more money do I have to have, and where can I get it?

You probably have heard stories of the highly successful merchant who went into business on a shoestring and now has the largest store in town. There is usually at least one of these rugged individualists in every community. But such stories, while true in the case of certain exceptional individuals, create the wrong impression of general conditions, and cause some service technicians to underestimate the amount of money they will need. In most cases, the person who started a business on a shoestring started it quite a number of years ago. The costs of merchandise, shipping, labor, and all the other costs of opening a retail hardware store were only a fraction of what they are today.

The Small Business Administration (SBA) exists to help the nation's small firms. It does this in a variety of ways. For instance, it helps small businesses get bank credit and capital. It helps them learn about new management

approaches through counseling, management courses, and publications. In fact, the SBA issues a number of publications designed to help small businessmen improve their management skills. The *Small Marketers Aids* especially will be of interest to the appliance shop owner because they deal specifically with common administration and management problems. Some of the *Management Aids* also deal with subjects that are applicable to the appliance service business—for example, financial management, loan sources, and so on. A complete list of titles may be obtained without charge from the nearest SBA field office or from the Small Business Administration, Washington, D.C. 20416. We recommend that you obtain those titles that pertain to the appliance servicing business.

Regardless of whether you are planning to go into business for yourself or are employed by an appliance service organization or firm, here are points of business practices which you should be concerned with.

Service Charge

For an appliance repair job the service charge must cover a great deal more than the labor expended, although this fee is usually computed from the service technician's working time. To aid in determining a time charge that will be fair to your firm's customers and reasonably profitable to the company, these hidden costs have been classified below into three groups.

Group 1. In addition to the overhead chargeable to the service department, an allowance should be included in the time-charge markup to cover the cost of miscellaneous supplies—which never appear separately on the customer's invoice—such as lubricants, cleaning fluid, sandpaper, tape, and asbestos string; under this classification we may also include perishable tools, such as files, drills, hacksaw blades, grinding wheels, and so on.

Group 2. Some lost time is unavoidable, for you must occasionally talk with customers, you must prepare and quote a few estimates every day (some of which will be rejected), you must telephone a jobber now and then to inquire about a delayed order, and, even if your firm has a secretary to typewrite parts purchase orders, you will have to gather the necessary information. Moreover, when parts shipments arrive, you or someone in your organization will have to unpack, check, and identify the parts, then allot the items ordered for specific jobs and revive inactive work orders so that the jobs which have been awaiting parts will be included in the next day's work, and finally, someone must put the remainder of the parts order in the proper stock bins. These necessary, though not directly productive, duties make it all but impossible for a company to collect for more than about 80 percent of everyday labor—and this proportion varies little with the number of service department employees. For example, if you are the only employee, about 20 percent of your time will be necessarily nonproductive; if there are three persons, two could be fully productive, but one would be a semiproductive supervisor; if an organization grows to the extent that it requires four or five employees, one of these will be a nonproductive supervisor.

Group 3. A reasonable allowance must be made for human error, for even the most conscientious and thoroughly skilled mechanic is not infallible. Of the three groups of indirect costs, however, this one is indeed the least—even trivial—but this allowance must be considered along with the rest. In this category will fall not only the reservicing of a repaired appliance under the terms of the service warranty, but also the one-in-a-hundred job which must be reworked before it leaves the bench because of a testing or an assembly error. This does not mean that every rework job is necessitated by a service technician's mistake, for sometimes you will unintentionally install a faulty new part—one which has suffered concealed damage in transit. Sometimes, after a thorough study of average time charges, it is possible to establish flat rates for most service operations. Table 9-1 gives typical flat fee rates for some popular appliances.

Let us at this point draw a line of distinction between a "free" estimate and one which is charged for, because the terminology is not

Table 9-1. **Small appliance flat-rate repair charge.**

Blender	$9.50
Can opener	7.25
Coffee maker	8.50
Fry pan	7.50
Iron (dry)	6.00
Iron (steam & spray)	9.00
Iron (travel)	6.75
Mixer (portable)	7.00
Mixer (stand)	11.25
Oven	8.00
Roaster	13.00
Rotisserie & broiler	14.50
Toaster (broiler)	8.00
Toaster (two-slice)	8.00
Toaster (four-slice)	9.75
Waffle iron	8.00
Minimum bench charge	5.00

wholly accurate in either of these two estimating policies. A "free" estimate is one for which no charge is collected when it is quoted if no work is done but the time charge for which becomes a part of the total fees if and when the estimate is approved. A nonfree estimate may be modified by some servicing dealers whereby they offer to apply a minimum service charge, collected at the time an estimate is quoted and held in abeyance, against the total repair charges or toward the purchase price of a new appliance to replace the faulty one.

Taking all the foregoing indirect costs into consideration, a suitable retail time charge for service operations may be arrived at by marking up the direct cost of labor from 100 to 150 percent. If this wide latitude of the suggested markup surprises you, bear in mind that even with equal skill and efficiency, the fixed operating or overhead costs will vary greatly with different shops. The computing of the hourly service charge, however, is the first of two steps in preparing your company's rate schedule.

For the final step, you should establish a base price for charges up to and including the first half hour, which would be somewhat higher for this initial period than for subsequent time charges for the same transaction. In other words, when you have fixed the retail hourly rate, increase the first half-hour charge by approximately 33 percent additional to arrive at this base price. Remember that handling costs will snatch a bigger bite from your markup as the selling priee of a service transaction goes down.

Let us say, for example, that you want to get $4/h for labor and, after studying the firm's fixed overhead, it is decided to use the minimum markup of 100 percent. This, of course, would make your hourly service rate $8. Now if a half hour is used as a minimum time charge ($4), plus 33 percent ($1.35) for the first hour as suggested above, your firm's rate schedule would read like this: $5.35 for the first half hour or fraction thereof, and $2 for each quarter hour thereafter.

For the pricing of parts most servicing dealers prefer to use each manufacturer's retail-parts price sheets even though the discount may be as low as 25 percent. Such a practice keeps prices uniform with those of the manufacturer and discourages embarrassing questions.

When making a house call to repair a major appliance, a travel time charge should be made. This is usually made on the same basis as the normal work rate. In suburban and rural areas, a mileage or trip charge is usually added to the house call charge. This charge is based on the distance (round-trip) from the shop to the resident where the repair is to be made.

Most appliance service shops work on a cash on delivery basis. In fact, almost all customers—even those with preferred credit, who buy everything else on open account—will expect to pay the service charge when they pick up a repaired appliance. Hence, it is no trouble to maintain a strict COD policy. You may wish to make an exception once in a while, but a uniform COD policy does help to hold down costs.

Guarantees and Warranties

When servicing *in-warranty* appliances, manufacturers give a service allowance to their servicing dealers for taking care of their own inwarranty sales. The amount of this fee is carefully worked out by each manufacturer to cover

the average cost of in-warranty service for a specific appliance. Generally, small appliances sold by your organization and returned for servicing within the warranty period should be sent to the nearest authorized service station for adjustment unless your company has been appointed an authorized servicing agent for the make in question. There are exceptions, however, as in the case of some minor exterior fault which involves merely the replacement of a control lever, terminal-enclosure cap, or the like. Most manufacturers will not object to your rendering some of these minor exterior services and nearly all will either exchange the part on its return or credit your firm's account for its net price. Needless to say, if permission is obtained to handle such minor in-warranty jobs in your own shop, not only will your customers enjoy quicker service in such instances, but also your organization will be money ahead, for postage and packing would surely exceed the cost of labor for such trivialities. But without the authorized service franchise, do not under any circumstances dismantle an in-warranty small appliance, because dismantling without authority constitutes tampering, and in such cases the manufacturer is privileged to void the guarantee. When in doubt, therefore, as to how far you may go in any specific case of this sort, be sure to contact the jobber first.

Most successful appliance servicing companies have established a fairly liberal policy for handling recalls. They have proved that they are money ahead in the long run. That is, it is wise to make reasonable and fair allowances for the unintentional faulty workmanship, which creeps in on the most conscientious worker occasionally, as well as for the unexplainable and untimely second failure of some part or adjustment. And do not forget that a repair part sometimes suffers concealed damage in transit.

Such troubles cannot be avoided entirely, but there are so few of them that most shops can easily afford to make an adjustment within a reasonable period of time and thus ward off disputes which could lose some good customers. There are differences of opinion as to how long one should guarantee a repair job—some favor 1 month, others 3, still others 1 year. Ordinarily, any defective parts or faulty workmanship in a repaired appliance will show up within 3 months, but to say that your firm will stand back of the work for 1 year gives your customers a unique sense of confidence in your organization's ability to turn out a good job. Furthermore, customers' questions relating to the duration of the guarantee are eliminated because the repair warranty matches that of a new appliance.

A repair warranty, however, is not a blanket protection against recurring trouble. Rather, your firm agrees to replace free of charge only the parts which you renewed if any of them prove to be defective within 1 year (or whatever period you choose) from date of installation. If any other parts fail within the guarantee period, your company agrees to replace these for the price of the parts only—that is, without a service charge.

Records and Forms

Whether you own your business or work for an employer, work-order forms are a must. The one shown in Fig. 9-1 is recommended by the National Appliance and Radio-TV Dealers Association, and most manufacturers will accept them for warranty payments. It has four sheets, each of which is a different color.

The original and two copies are issued to the service technician when the job is assigned. When the work is completed, the original is filed alphabetically as the shop record, while one copy serves as the customer's receipt. The second copy, if it pertains to an in-warranty call, is sent to the manufacturer as proof of service. When work is assigned by telephone to a service technician, the customer can be given a simple cash receipt and told that a detailed invoice will be mailed the next day.

The fourth copy remains in the office, where, during the day of assignment, it is placed in the service technician's folder. When the work is completed, the fourth copy can be filed numeri-

NAME		NO. 20N 017138
ADDRESS	APT.	DATE RECEIVED / / ☐ A.M. ☐ P.M.
CITY	AREA CODE PHONE	DATE PROMISED / / ☐ A.M. ☐ P.M.
STATE	ZIP	BRAND/PRODUCT
CUSTOMER REQUEST		MODEL NO.
		SERIAL NO.
DESCRIBE WORK DONE		DATE INSTALLED OR SOLD / /
		DATE FAILED / /
SOLD BY	FAILURE CODE A B C D E F H I J K	WARRANTY SERVICE CHARGE

QTY.	PART NO.	DESCRIPTION	PARTS DISPO.	UNIT PRICE	AMOUNT

TECHNICIAN NO.

I certify that I have performed services indicated and installed parts listed.

TECHNICIAN SIGNATURE

CUSTOMER SIGNATURE

X

I acknowledge that repairs have been performed in a manner satisfactory to me.

DATE	TIME BEGIN	TIME END
/ /		
/ /		

TOTAL MATERIAL	
TRIP CHARGE	
SERVICE	
SUB TOTAL	
STATE TAX	
LOCAL TAX	
TOTAL	

Not Home ☐ Lack Part ☐ Call Back ☐

Demand ☐ __ Warr. ☐ __ Other Warr. ☐ __ Cont. ☐ __ Sales ☐ __ Misc. ☐ __

OTHER DIST. STORE

Dealer's Signature__________________

Figure 9-1. Work form recommended by the National Appliance and Radio-TV Dealers Association.

cally. This file will serve two purposes: to locate an order by number when the name in unknown, and to establish a chronological record of service business received. From this record you can tell in a moment, by subtracting one serial number from another, how many calls were received for any given period.

WORK HABITS

Personal Traits and Attitudes

Ordinary good manners and a refined personality are taken for granted here, but experience has proved that many persons do not at first fully realize the need for a special kind of business courtesy when dealing with service customers. So that you do not overlook any of the seemingly obvious details, the suggestions which follow are intended to highlight the main points of good service-business behavior. Also included under this head are a few of the more common unintentional blunders, some of which border on rudeness.

Let us begin at your service counter, where an imaginary customer is waiting, holding a small appliance. Both are ailing, one emotionally, the other physically, and both are to be mended in your establishment. The customer comes first. That is, many customers come to an appliance repair shop in a state of distress (some even with a chip on the shoulder). This cannot be overemphasized and, further, it is your responsibility to ease that tension as quickly as possible. To this end, get the customer's name immediately after greetings have been exchanged so that in the ensuing conversation you may address the customer by name. Before taking any further information for the repair tag, however, you should listen with sincere interest to the customer's tale of woe.

Almost every customer will want to know when the repair job will be completed. And though prompt service is a selling point, a reasonable time must be allowed for processing the work so that every job can be finished in good time. Usually, the 3-day method of scheduling (receive it today, repair it tomorrow, issue completion notices the day after) is acceptable to most customers and will allow you to plan your work systematically. When a delay is unavoidable, however, the customer should be informed well in advance of the originally promised completion date.

When a customer calls for a repaired appliance and says that the claim check has been misplaced or forgotten, the traditional laundryman's quip, "no tickee, no shirtee," need not be the rule for your service organization. For positive identification—if the person is not remembered—ask for the name and address and a description of the appliance; then compare this information with the job record and, if in agreement, the appliance may be delivered without fear of giving it to the wrong person. But inasmuch as a receipt was given to the customer when the appliance was accepted for repairs, a receipt should also be taken when the appliance is returned. That is, be sure to ask the customer in such cases to sign the sales slip covering the transaction on the *received by* line.

Almost all service technicians are inclined to occasionally express opinions regarding the quality of the products on which they work. We all know that such appraisals are stimulated not only by their knowledge of the inner workings of certain appliances and machines, but also by the questions put to these people by friends and relatives seeking "inside information" prior to making a purchase. But you must be ready with a courteous and neutral answer to such questions, for this sort of information amounts to nothing more than an opinion, having no basis in fact, and hence is of little or no value in any event. Furthermore, see that nothing in your attitude, conversation, or gestures even hints to a customer that an appliance brought to you for service is in any way inferior to any other—no matter what you think about it. Indeed, a thoughtless slip of the tongue in this respect can be taken as a gross insult.

One must be careful, too, how one says, "We do not repair this make"—if you do not repair

every make. Moreover, you must be ready with a tactful answer to the question "Why?" which is certain to follow the foregoing statement. And do not become involved in the highly controversial subjects of conversation such as politics, religion, intimate family matters, interracial relations, and so forth. Experience has proved that service people rarely originate such discussions, but often they are innocently drawn in. Some customers, when reciting their appliance troubles, will suddenly go off on a tangent and start talking about anything and everything from marital mishaps to politics. Shy away gracefully from such topics.

On the rare occasion when a recently repaired appliance is returned to your shop for reservicing, you must exercise the utmost tact and self-control, because in some instances you may be the object of a scalding initial outburst such as, "My iron is worse than it was before!" or "What did you do to my toaster?" This sort of irate customer is easily disarmed. If you will admit that you might have overlooked some detail and express regret that the customer has been inconvenienced by your oversight, the situation is bettered immediately. If a specific case of this kind calls for more balm, you could offer to do the rework job ahead of its turn—even the same day, if possible. Strangely, these infrequent reservicing jobs strengthen the ties between you and your customer, for when he or she calls for the reworked job and learns that you did make good your guarantee and the transaction was handled as promptly and as courteously as the original job, that customer's appraisal of the quality of your service shoots up immeasurably. Often, it seems we are more critically judged by the manner in which we correct our errors than by our everyday actions.

Safety

Safety is always of primary importance. You must consider safety for yourself as you work, safety for the surroundings in the area which you are working, and safety for the customer after you leave the job.

Safety for yourself includes using the approved eye protection, using grounded tools and instruments, employing proper lifting and moving practices, and being aware of and prepared for any emergency that might arise as you work. You may use shortcuts and unsafe practices for years with no adverse effects, but the one time that you are caught can make all the time you have saved very expensive. It must be remembered, for instance, that every electric circuit is dangerous. Failure to observe this fundamental principle can be fatal. Also keep in mind that points of negative potential are as dangerous as positive potential. Let us consider Fig. 9-2. In A the negative terminal is grounded. Examination of the illustration shows clearly that the *figure* standing on the ground and with one hand on the positive terminal of the power source

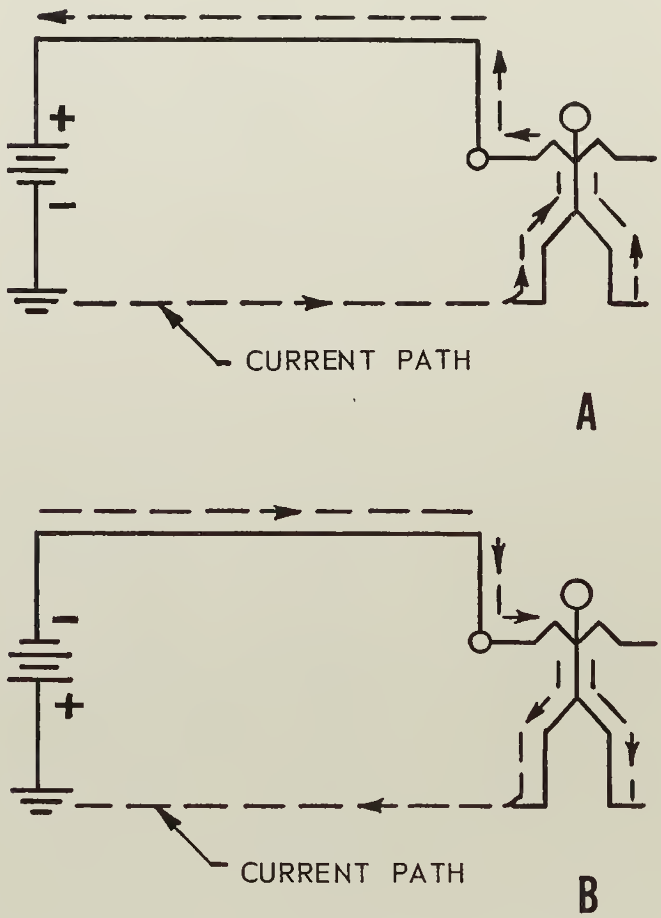


Figure 9-2. Points of negative and positive potential are equally dangerous.

which is connected directly across it. In Fig. 9-2B, the positive terminal of the power source is connected to ground. This does not mean that it is safe to handle the negative terminal. Comparison of Figs. 9-2A and 9-2B shows that, in both illustrations, the figure is connected directly across the power source. The negative terminal in Fig. 9-2B is just as hot as the positive terminal in Fig. 9-2A. The only difference is the direction of current through the figure, and current from head to toes can be just as fatal as current from toes to head. Current through the body is limited only by the resistance of the body. Under certain conditions the body resistance may be very low and a very low voltage may produce a fatal current.

It is also important to keep in mind that ground may be at any point in the circuit. In the simple circuit of Fig. 9-3, the junction of R_1 and R_2 is grounded. Arrowheads on the lead wires indicate the direction of current. Assuming that R_1 equals R_2, point *A* is 500 V positive with respect to ground *G*; point *B* is 500 V negative with respect to point *G*. Although it is negative, point B is as dangerous as point *A*. Also note that, if a person standing on the ground places one hand on point *A* and the other hand is on point *B*, there is a potential difference of 1,000 V between his hands.

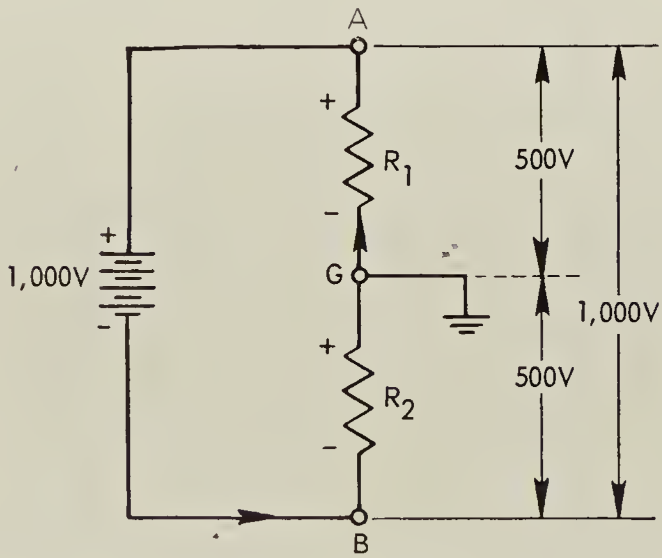


Figure 9-3. Ground may be at any point.

Do not assume that a certain point is at ground potential. Keep one hand in your pocket to avoid the possibility of connecting yourself between two points between which there is a potential difference. Care is more in safety. Remember there is *always* time for safety.

Safety for the surroundings means respect for the property around which you are working. Cover furniture and rugs that could be damaged. Do not track the dirt on your shoes into the house. Direct the discharge of refrigerant out of doors, being sure that shrubs, flowers, or grass are not damaged by the refrigerant. Use extreme caution when moving the appliance. With the rugs and carpets being used in kitchens today, moving an appliance can become troublesome. The goodwill derived from a successful service call can be nullified when property has been damaged or the work area has been left dirty.

Before leaving, be certain that the product is properly grounded and that the outlet into which the appliance is to be plugged is properly grounded. If there is any doubt that the receptacle is functioning properly, advise the customer. Note on the work order that the customer has been advised and have the customer sign it, if possible. Advise the customer to contact an electrician who can wire the receptacle to meet the local codes.

Safety does not cost; it pays. Give electricity the respect that it deserves. In fact, there are five good safety rules to follow when servicing electrical appliances:

1. Never stand on a wet surface.
2. Use insulated tools.
3. Remove the service cord from the outlet or fuses from the disconnect switch.
4. Never touch a wire while in contact with a water pipe or a device connected to a pipe.
5. Treat every circuit as if it were a live one.

The Golden Rules for Service Technicians

What makes a good service technician? Here are the "golden rules" that all service technicians should follow.

1. *Honesty.* A service technician's time is actually money. Honesty with both customer and employer in indicating correct time, parts usage, and work performed on all work orders in important.
2. *Pride.* The service technician should take pride in performing a professional job.
3. *Tact.* A service technician should recognize that tactfulness and diplomacy are necessary in all walks of life, but particularly on jobs covering direct relations with the public. Service contacts oftentimes require the utmost in tact and courtesy.
4. *Helpfulness.* A service technician should feel a genuine spirit of helpfulness in repairing the equipment and offering suggestions for better use of the product.
5. *Loyalty.* A service technician should be loyal in all statements concerning the products which are serviced, the company which makes the products, and the service organization.
6. *Cooperativeness.* The service technician should be a part of the overall organization, always mindful of an opportunity to assist other members whenever possible.
7. *Consideration.* A service technician spends many working hours handling other people's property and equipment. The utmost care and consideration must be given to the property, equipment, and premises.
8. *Attentiveness.* A service technician should exercise patience in listening to the user's story. Attentiveness to the user can often help diagnosis, and it is certainly conducive to better relations. Conversely, the service technician should be articulate and able to express ideas clearly, in proper language.
9. *Neatness.* A service technician should have a neat appearance. Work clothes should be clean and orderly. The customer's impression of the dealership, and in many cases the product itself, is often formed by the general appearance of the service technician.
10. *Friendliness.* One should recognize that the ability to get along with people is as important in service work as in sales. A good personality can be cultivated to a great degree by learning to like people.

Glossary of appliance servicing terms

APPENDIX

A

Abrasive. A material or compound used for grinding or polishing.

Absolute humidity. The amount of moisture in the air, indicated in grains per cubic foot.

Absolute pressure. Gauge pressure plus atmospheric pressure (14.7 lb/in^2).

Absolute temperature. The temperature measured from absolute zero.

Absorbent. A substance which has the ability to take up or absorb another substance.

Ac. Alternating current.

Ac-dc Refers to an electrical device which operates on either alternating or direct current.

Ac generator. A generator that is a source of alternating current.

Accelerate. To speed up or make go faster.

Accumulator. The storage tank which receives liquid refrigerant from the evaporator and prevents it from flowing into the suction line.

Activate. To make active; to put into motion or work.

Additive. A substance which is added to something else to make it perform better.

Affix. To attach or connect one device or material to another.

Agitate. To shake jerkily; to put or keep in irregular motion.

Agitation. The act of being shaken or stirred roughly.

Agitator. That part of an agitator washing machine which excites the water to produce the washing action in conventional models and both the washing and rinsing actions in automatics.

Air, primary. The air necessary for combustion that is mixed with the gas in a burner before ignition takes place.

Air, secondary The air surrounding a flame that is necessary to complete combustion.

Air cleaner. A device used for the removal of airborne impurities.

Air conditioner. A device used to control temperature, humidity, cleanliness, and movement of air in a conditioned space.

Air-cooled condenser. A condenser in which the heat of compression is transferred from the condensing coils to the surrounding air. This may be done either by convection or by a fan or blower.

Air cooler. A mechanism designed to lower the temperature of the air passing through it.

Air gap. The space between the rotor and the stator of a motor. Also a type of valve used in wet-pickup central vacuum cleaning systems. Also the space between the end of a fill-hose and the tub into which water flows.

Air-sensing thermostat. A thermostat unit in which the sensing element is located in a refrigerated space.

Alignment. The act of being brought into a straight line.

Alligator clip. A clamp-type temporary wire connector.

Alnico. A metal alloy used in permanent magnets.

Alternating current. Electric current in which the electrons move first in one direction and then in the other.

Ambient temperature. The temperature of the surrounding air or material.

Ammeter. An instrument for measuring the amount of electron flow in amperes.

Ampere. The basic unit of electric current.

Ampere-turn. The magnetizing force produced by a current of one ampere flowing through a coil of one turn.

Amplification. The process of increasing the strength (current, power, or voltage) of a signal.

Amplifier. A device that increases the strength of an electronic impulse.

Amplitude. The maximum instantaneous value of an alternating voltage or current, measured in either the positive or negative direction.

Annealing. Process of heat-treating metal to obtain the desired properties of softness and ductility (being easy to form into a new shape).

Anode. The positive terminal of an electrolytic cell.

Antisiphon loop. A loop in a drain hose extending above the normal water level of a tub to prevent unwanted water drainage.

Apparent power. The product of volts times amperes when they are in phase. (Not found in most ac circuits. Must be multiplied by a power factor for real power.)

Appliance ground. A conductor leading from the chassis or cabinet of an appliance to a solid ground connection. It prevents the shocking of the appliance user in the event of a short-circuited component. The fuse will blow first.

Arc. A flash caused by an electric current ionizing a gas or vapor.

Armature. The rotating part of an electric motor or generator. Also the moving part of a relay or vibrator.

Atmospheric pressure. Pressure that gases in

the air exert upon the earth, measured in pounds per square inch.

Atom. The smallest particle of an element that can exist alone.

Atomize. To make a liquid into a fine spray.

Attachment plug. The plug on the end of a cord set used for connecting to the power supply.

Attenuator. A network of resistors used to reduce the voltage, current, or power delivered to a load.

Automatic defrost. A system which removes ice and frost accumulation from the evaporator automatically.

Automatic ice cube maker. A refrigerating mechanism designed to automatically produce ice cubes in quantity.

Autotransformer. A transformer in which the primary and secondary coils are connected together in one winding.

Back pressure. Pressure in the low side of a refrigerating system; also called *suction pressure* or *low-side pressure.*

Bake unit. A heating unit used in the bottom of a baking enclosure.

Balanced circuit. A circuit with equal voltage and current flow across and through all its branches.

Ball check valve. A ball valve which permits the flow of fluid in one direction only.

Ballast. An inductance coil or transformer which is used with a fluorescent tube.

Bath. A liquid solution used for cleaning, plating, or maintaining a specified temperature.

Battery. Two or more primary or secondary cells connected together electrically. The term does not apply to a single cell.

Bearing. A low-friction device for supporting and aligning a moving part.

Bellows. A corrugated cylindrical container which moves as pressures change, or one which provides a seal during movement of parts.

Beveled. Cut at an angle; not a right angle; sloped.

Bezel. A sloping or slanting surface, as the cutting edge of a chisel.

Bimetal. Two dissimilar metals, with different rates of expansion, bonded together. When heated, the assembly will buckle or bend. Mostly used in temperature-actuated switches to make and break contact points.

Bimetal strip. Temperature-regulating or -indicating device which works on the principle that two dissimilar metals with unequal expansion rates, welded together, will bend as temperatures change. Same as *bimetallic blade.*

Bleed. To come through or show through a covering coat of paint. (To ooze sap, juice, etc., as a bruised plant.)

Bleed valve. A valve with a small opening inside which permits a minimum fluid flow when the valve is closed.

Bleeder. A resistor connected between capacitor terminals to minimize arcing of the points of a voltage-type relay.

Boil. To heat a liquid to a point where bubbles of vapor rise and break at the surface.

Boiling temperature. Temperature at which a fluid changes from a liquid to a gas.

Bore. The inside diameter of a cylindrical hole.

Boss. A reinforcing protrusion surrounding an opening.

Bourdon tube. Used in pressure gauges; a thin-walled tube of elastic metal, flattened and bent into a circular shape, which tends to straighten as pressure inside is increased.

Brazing. The method of joining metals with a nonferrous (without iron) filler using heat between 800°F and the melting point of the base metals.

Breaker points. Metal contacts that open and close a circuit at timed intervals.

Breaker strip. A strip of wood or plastic used to cover the joint between the outside case and the inside liner of a refrigerator.

Breather hole. A pressure-equalizing vent situated well above the oil level in a closed mechanism which uses fluid lubricant.

Bridge. A connection between two parallel circuits.

Bridge circuit. Any one of a variety of electric circuit networks, one branch of which, the "bridge" proper, connects two points of equal

potential and hence carries no current when the circuit is properly adjusted or balanced.

Bridge rectifier. A full-wave rectifier with four elements connected in series as in a bridge circuit. Alternating voltage is applied to one pair of opposite junctions, and direct voltage is obtained from the other pair of junctions.

Broiler unit. A heating unit usually located in the ceiling of an ovenlike enclosure.

Brush. The conducting material, usually a block of carbon, bearing against the commutator or slip rings through which the current flows in or out.

Btu. British thermal unit. The heat required to raise the temperature of one pound of water one degree Fahrenheit.

Bulb, sensitive. Part of a sealed fluid device which reacts to the temperature to be measured, or which will control a mechanism.

Bus bar. A primary power-distribution point connected to the main power source.

Bushing. A metal lining used for making the effect of friction on moving parts less; it can be taken out.

Butane. A liquid hydrocarbon commonly used as fuel for heating purposes.

Bx cable. A flexible metallic armor for covering wires for protection.

Bypass. Passage at one side of, or around, a regular passage.

Calcium. A soft, silver-white metallic element found combined with limestone, chalk, marble, etc. Also an element that is often dissolved in water causing "hardness."

Calibrate. To adjust to a known standard or norm.

Calorie. The amount of heat required to raise the temperature of one gram of water one degree centigrade.

Cam. A wheel, or projection on a wheel, which gives an alternating or irregular motion to a wheel or shaft—or a device which gets its irregular motion from such a wheel. Also, an irregular-shaped rotating or sliding part used to change circular motion to up-and-down motion.

Capacitance. The factor in an electric circuit that opposes a change in voltage. The ability of a circuit to store an electrostatic field. Distributed capacitance in a circuit is the result of adjacent loops on coils and parallel leads.

Capacitive reactance. The opposition to alternating current flow due to capacitance in the circuit.

Capacitor. Two electrodes or sets of electrodes in the form of plates, separated from each other by an insulating material called the *dielectric.*

Capacitor-start motor. A motor which has a capacitor in the starting circuit.

Capillary tube. A type of refrigerant control, usually consisting of several feet of tubing having a small inside diameter. Friction of the liquid refrigerant and bubbles of vaporized refrigerant within the tube serve to restrict the flow so that the correct high-side and low-side pressures are maintained while the compressor is operating. A capillary-tube refrigerant control allows high-side and low-side pressures to balance during the OFF cycle. Also, a small-diameter tubing used to connect temperature-control bulbs to control mechanisms.

Casehardened. Refers to a process in which heat-treated ferrous metals (iron) are used to make the surface layer harder than the interior.

Cathode. That portion of a vacuum tube which is negatively charged.

Center post. The column which supports the upper end of a washing machine's agitator-drive shaft.

Center tap. A wire tap made to the center of a coil.

Centigrade scale. The temperature scale used in the metric system. The freezing point of water is 0°C; the boiling point is 100°C.

Centimeter. A metric unit of linear measurement which equals 0.3937 in.

Centrifugal force. The force which causes objects to move away from the center of rotation due to inertia (the tendency of a body to stay at rest or keep moving in the same direction unless acted on by an outside force).

Centrifugal pump. A pump which utilizes

centrifugal force to move a liquid or a gas, as distinguished from one using one or more pistons and cylinders.

Centrifugal starting switch. A switch which opens a motor's starting-winding circuit by centrifugal force as the motor approaches normal running speed.

Chassis. The frame or baseplate to which the appliance components are attached.

Check valve. A device which permits fluid flow only in one direction.

Chemical refrigeration. A system of cooling in which a chemical disposable refrigerant is employed.

Choke. An inductance used in a circuit to present a high impedance to frequencies without appreciably limiting the flow of direct current. Also called a choke coil. A groove or other discontinuity in a waveguide so shaped and dimensioned that it impedes the passage of guided waves within a limited frequency range.

Choke coil. A coil of low ohmic resistance and high impedance to alternating current.

Circuit. The complete path of an electric current.

Circuit, parallel. Arrangement of electrical devices in which all positive terminals are joined to one conductor and all negative terminals to the other conductor.

Circuit, series. An electric path (circuit) in which electricity to operate a second lamp or device must pass through the first, and so on; current flow travels through all devices connected together.

Circuit breaker. An electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a predetermined amount. Circuit breakers can be reset.

Circular mil. An area equal to that of a circle with a diameter of 0.001 in. It is used for measuring the cross section of wires.

Closed circuit. A circuit that is complete and allows current to flow.

Clutch. That part of a mechanism which may be shifted, either automatically or by an operator, depending upon the design, to couple driven parts with their driving members as well as to uncouple one from the other.

Clutch gear. A gear which performs part of the function of a clutch, some of which have, in addition to their teeth, a gripping contrivance to match that of the clutch.

Coil. A wire conductor wound on a form.

Cold. Cold is the absence of heat; a temperature considerably below normal.

Cold wall. A type of refrigerator which has the inner lining serving as the cooling surface.

Collector ring. A disk or collar on a rotating part by which electric contact is made with a stationary member.

Combustible. Able to be burned up; inflammable.

Commutator. The copper segments on the armature of a motor or generator. The commutator is cylindrical in shape and is used to pass power into or from the brushes. It is a switching device.

Compensator. In an electric toaster, a device intended to automatically alter the time cycle to suit any starting temperature.

Components. One (or more) of the parts of a whole.

Compound circuit. Circuits of resistances connected in series and in parallel.

Compound gauge. A device, used in refrigeration, which measures pressures below the atmospheric pressure as well as those above the atmospheric pressure.

Compression. Denotes an increase of pressure on a fluid as a result of applied mechanical energy.

Compression gauge. An instrument used to measure positive pressures (above atmospheric pressure) only. These gauges are usually calibrated from 0 to 3,000 lb/in^2 of pressure.

Compressor. The pump of a refrigerator mechanism which draws a vacuum on the low-pressure (cooling) side of a refrigerant cycle and squeezes or compresses gas into the high-pressure (condensing) side of the cycle.

Condensation. Liquid or droplets which form when a gas or vapor is cooled below its dew point.

Condense. To change a gas or vapor to a liquid.

Condenser. Another name for a capacitor. Also a device which changes gases or vapors to a liquid.

Condenser cooling fan. A fan which circulates air over the exterior surfaces of a refrigerator's condenser.

Condensing unit. That part of a refrigerating mechanism which pumps vaporized refrigerant from the evaporator, compresses it, liquefies it in the condenser, and returns the liquid refrigerant to the refrigerant control.

Conductance. The ability of a material to conduct or carry an electric current. It is the reciprocal of the resistance of the material, and is expressed in *mho's.*

Conductivity. The ease with which a substance transmits electricity.

Conductor. Any material suitable for carrying electric current.

Conduit. A rigid-metal or fiber tube through which wire conductors are run for protection.

Connecting rod. That part of a compressor which connects the piston to the crankshaft.

Connection. The joining of two or more parts.

Connectives. Devices which connect or join two or more things together.

Constrictor. A tube or orifice used to restrict the flow of a gas or a liquid.

Contactor. A magnetic relay switch with contact points which usually open and close high-voltage circuits. It is actuated by a low-voltage magnetic coil.

Contacts. The points in a switch where circuits are made and broken.

Contaminant. A substance (dirt, moisture, etc.) foreign to the refrigerant or the refrigerant oil in a refrigeration system.

Control. An automatic or manual device used to stop, start, and/or regulate the flow of gas, liquid, and/or electricity.

Control bulb. The extreme end of the tube of a bellows-type control (which usually is slightly enlarged) where thermal contact is made.

Convection. The transfer of heat by means of the movement or flow of a liquid or gas.

Converter. A device for changing alternating current to direct current.

Cooling coil. An air conditioner's evaporator.

Corbin pliers. A type of hose-clamp pliers.

Cord guard. A spring or rubber sleeve on an appliance cord which is intended to prevent sharp bending where the cord enters its terminal enclosure.

Cord set. A fully assembled appliance cord with its appurtenances. Same as *line cord.*

Core. A magnetic material that affords an easy path for magnetic flux lines in a coil.

Core losses. Losses in a motor, generator, or a transformer caused by eddy currents and hysteresis.

Corrosion. A gradual wearing away, as by the action of chemicals; rust. A material made by the wearing away of a metal by chemicals.

Coulomb. The standard electrical unit of quantity measure. It is 6.3 billion billion electrons. 1 A is a flow of 1 C/s.

Counter-emf. Counter electromotive force; an emf induced in a coil or armature that opposes the applied voltage.

Counterflow. Flow in an opposite direction.

Coupling. A device by which one part of a machine is united with another.

"Cracking" a valve. Opening a valve a small amount.

Crimp. To squeeze or contract.

Crocus cloth. A fine sandpaper used to smooth a surface.

Curd. A deposit formed by the reaction of soap with hard water.

Current. The flow of electrons through a conductor, measured in amperes.

Current limiter. A protective device similar to a fuse, usually used in high-amperage circuits.

Cut-in. A temperature or pressure valve which closes a control circuit.

Cut-out. Temperature or pressure valve which disconnects between circuits.

Cycle. A complete positive and a complete negative alternation of a current or voltage.

Cylinder head. The part which encloses the compression end of a compressor cylinder.

Damper. A valve for controlling air flow.

Dc. Direct current.

Deceleration. A slowing down in speed or motion.

De-energize. To disconnect a component or circuit from the power source.

Deflection. The deviation of a meter indicator from 0.

Defrost. To melt and do away with frost and ice.

Defrost cycle. The refrigeration cycle in which the evaporator's frost and ice accumulation is melted.

Defrost timer. A device connected into an electric circuit which shuts the unit off long enough to permit the ice and frost accumulation on the evaporator to melt.

Defrosting. The process of removing frost accumulation from the evaporator.

Degreasing. The removal of oil or grease from refrigerator parts, usually done with a solution or solvent.

Dehumidifier. A device used to remove moisture from the air in an enclosed space.

Dehydrate. To remove water from; to become dry; to lose water.

Delta connection. The connection of three-phase alternators and transformers in which the start end of one winding is connected to the end of the second.

Demagnetization. The removal of magnetism from a substance.

Demand. The amount of power a power company must have available at a given time.

Density. Closeness of texture or consistency.

Deodorizer. A device which absorbs various odors, usually by the principle of absorption. Activated charcoal is a common substance used in such a device.

Desiccant. A substance used to collect and hold moisture in a refrigerating system. A drying agent. Two common desiccants are activated alumina and silica gel.

Detergent. A cleaning agent, like soap, but made from synthetics, not from fats and lye.

Determine. To set limits; bounds; to decide upon; to be a deciding factor; to give a definite aim to, to direct.

Device. An invention; a mechanical contraption, tool, or method.

Device control. A control used to operate a refrigerating system in such a way as to provide melting of the accumulated ice and frost.

Dew point. The temperature at which water vapor (at 100 percent humidity) begins to condense and deposit as a liquid.

Diagonal pliers. Pliers which will cut wire close to a terminal, even in tight places.

Diaphragm. A flexible membrane, usually made of thin metal, rubber, or plastic.

Dielectric. An insulator; a term that refers to the insulating material between the plates of a capacitor.

Dielectric heating. A process of heating by the application of an alternating current field. The heating is the result of molecular friction.

Dielectric strength. The ability of an insulator to withstand a potential difference.

Differential. As applied to refrigeration and heating, the difference between "cut-in" and "cut-out" temperature or pressure of a control device.

Diode. A two-element electron tube or device which will allow substantially more electron flow in one direction in a circuit than in the other direction.

Direct current. An electric current that flows in one direction only.

Distribution. A system for supplying electric power to various points.

Door switch. A switch which is actuated by the movement of a door.

Double-throw switch. A switch which will connect one (or one group) of its poles with either of two (or two groups) of its other poles, but not simultaneously.

Drain. To make or become gradually dry or empty.

Drier. A substance or device used to remove moisture from a refrigeration system.

Drill rod. Highly polished carbon steel rod of uniform diameter.

Drip pan. A pan-shaped panel or trough used to collect condensation from an evaporator coil.

Dry bulb. An instrument with a sensitive element which measures ambient air temperature.

Dry-bulb temperature. Air temperature as indicated by an ordinary thermometer.

Dry-cell battery. An electrical device, used to provide dc electricity, having no liquids in the cells.

Dry ice. A refrigerating substance made of solid carbon dioxide which changes directly from a solid to a gas (sublimates). Its subliming temperature is −109°F.

Dry run. An operating test conducted without loading the appliance.

Dryer sensor. A device in a dryer that eliminates overdrying of clothes by detecting the remaining moisture content in the clothes.

Duplex cable. A two-wire conductor with the wires insulated from each other and enclosed in a single insulated covering.

Duplex receptacle. A double-outlet receptacle in house wiring, providing outlets for connection of lamps and appliances.

Eddy current. Induced circulating currents in a conducting material that are caused by a varying magnetic field.

Effective resistance. The ratio between the true power absorbed in a circuit and the square of the effective current flowing in a circuit.

Effective temperature. The overall effect on a human of air temperature, humidity, and air movement.

Efficiency. The ratio of output power to input power, generally expressed as a percentage.

Ejector. A device which expels or discharges what is not wanted.

Electri-heat defroster. A defroster which uses an electric heater to melt frost from the evaporator as distinguished from the "hot gas" and other systems.

Electrolysis. The breakdown of two dissimilar materials caused by an electric current passing between them. The current may either be impressed or self-induced.

Electrolyte. A solution of a substance which is capable of conducting electricity. An electrolyte may be in the form of either a liquid or a paste.

Electromagnet. A magnet made by passing current through a coil of wire wound on a soft iron core.

Electromotive force. The force that produces an electric current in a circuit.

Electron. A negatively charged particle of matter; high-speed, negatively charged particle forming the outer shell of an atom; the smallest electric charge that can exist.

Electrostatic. Having to do with static electricity, that is, electricity at rest.

Elements. Substances which, either singly or in a combination with other elements, form all matter contained in the universe.

End-cutting pliers. Pliers having cutting jaws whose edges are horizontal and at right angles to its handles.

Energy. The ability or capacity to do work.

Entrance box (fuse panel). The metal box in which the main fuses or circuit breakers are mounted. The building circuits are connected to the entrance cable at this point.

Epoxy (resins). A synthetic plastic adhesive.

Escutcheon. A shieldlike disk or plate which is sometimes used merely for ornamentation or as a nameplate, but more frequently for trimming an opening where a control shaft emerges.

Eutectic point. The point at which a eutectic alloy will suddenly melt. A eutectic alloy is a composition of two or more metals that has one sharp melting point and no plastic range.

Evacuate. To withdraw from; to make empty; to remove the contents from.

Evaporation. A term applied to the changing of a liquid to a gas. Heat is absorbed in this process.

Evaporator. The cooling coil of a refrigerator wherein the vapor of boiling refrigerant absorbs and carries away heat.

Expansion valve. A device in a refrigerating system which maintains a pressure difference between the high side and low side. It is operated by pressure.

Factor of safety. A designated load, usually above the normal operating load of a circuit, component, or device, that can be handled without damage or hazard.

Fahrenheit scale. On a Fahrenheit thermometer, under standard atmospheric pressure, the boiling point of water is 212° and the freezing point is 32° above zero on its scale.

Fan. A radial- or axial-flow device used for producing artificial currents of air.

Farad. The unit of capacitance.

Feedback. A transfer of energy from the output circuit of a device back to its input.

Feeler gauge. A precision instrument comprising an assortment of metal leaves of graded thicknesses for measuring clearances in thousandths of an inch between electrical or mechanical parts.

Ferrite. A powdered, compressed, and sintered magnetic material consisting chiefly of ferric oxide combined with one or more other materials. Its high resistance makes eddy-current losses extremely low at high frequencies.

Ferrite core. A magnetic core made from ferrite; ferrite is a material composed of iron and other metals such as zinc, nickel, or manganese.

Ferromagnetic. A highly magnetic material such as iron, nickel, steel, etc.

Field. A space containing electric or magnetic lines of force.

Field coil. The stationary electromagnet in a commutator-type motor.

Field magnets. Electromagnets in the field of a generator or motor.

Field winding. The coil used to provide the magnetizing force in motors and generators.

Filament. A wire which, when heated with an electric current, emits electrons.

Fill circuit. The circuit which serves the water-intake-valve solenoids in a washing machine.

Fill valve. A device that allows water to enter the machine, generally operated by a pressure switch.

Filter. A device for removing small particles from a fluid or from air.

Filter capacitor. A capacitor used in a power-supply filter system to provide a low-reactance path for alternating currents, and thereby suppress ripple currents, without affecting direct currents. Electrolytic capacitors are generally used for this purpose.

Finned-type condenser. A condenser whose tubing is surrounded with fins to speed dissipation of its heat.

Flange. A rim or collar on a wheel which sticks out to hold the wheel in place, give it strength, or attach it to something else.

Flash point. The temperature at which an oil will give off sufficient vapor to support a flash flame but will not support continuous combustion.

Flexible coupling. A coupling having one or more resilient members which are intended to absorb vibration occasioned by slight misalignment between the centers of the shafts it couples and serving also, in some cases, to insulate (electrically) one shaft from the other.

Float switch. A switch which is actuated by the movement of a float.

Float valve. A type of valve which is operated by a sphere or pan which floats on a liquid surface and controls the level of the liquid.

Flow-interlock switch. A device installed in a water line which will hold an electric circuit open until water flows through the line at a predetermined velocity.

Fluid. A substance in a liquid or gaseous state; a substance containing particles which move and change position without separation of the mass.

Flux. Lines of magnetic force.

Flux density. The number of lines of flux in an area of magnetic force.

Flux field. All the electric or magnetic lines of force in a given region.

Foaming. The formation of a foam in an oil-refrigerant mixture due to rapid evaporation of refrigerant dissolved in the oil. This is most

likely to occur when the compressor starts and the pressure is suddenly reduced.

Foot-pound. A unit of work. A foot-pound is the amount of work done in lifting one pound one foot.

Force. Force is an accumulated pressure and is expressed in pounds. If the pressure is 10 lb/in^2 on a plate of 10-in^2 area, the force is 100 lb.

Forced convection. Movement of fluid by mechanical force, such as fans or pumps.

Free electrons. Electrons which are loosely held and consequently tend to move at random among the atoms of the material.

Freeze-up. The formation of ice in the refrigerant control device which may stop the flow of refrigerant into the evaporator.

Freezing. The change of state of a substance from liquid to solid.

Freezing point. The temperature at which a liquid will solidify upon removal of heat. The freezing temperature for water is 32°F at atmospheric pressure.

Freon. A special gas used in refrigeration.

Frequency The number of complete cycles per second existing in any form of wave motion; such as the number of cycles per second of an alternating current.

Friction-wheel clutch. A clutch in which the tread of a metal wheel may be engaged with the tread of a wheel having a resilient tire.

Full-load voltage. The source voltage available when full-load current is being drawn.

Full-wave rectifier circuit. A circuit which utilizes both the positive and the negative alternations of an alternating current to produce a direct current.

Fuse. A protective device inserted in series with a circuit. It contains a metal that will melt or break when current is increased beyond a specific value for a definite period of time.

Fusible. Able to be united as if melted together.

Gain. The ratio of the output power, voltage, or current to the input power, voltage, or current, respectively.

Galvanometer. An instrument used to measure small direct currents.

Gas. The vapor phase or state of a substance.

Gas valve. A device for controlling the flow of gas.

Gasket. A resilient or flexible material used between mating surfaces to provide a leakproof seal.

Gauge manifold. A device constructed to contain both compound and high-pressure gauges and valved to control the flow of fluids through the unit.

Gear motor. A motor which has a gear box as an integral part, which affords one or more ratios of speed and power differing from the actual output of the motor itself.

Generator. A machine that converts mechanical energy into electrical energy.

Genuine parts. Parts supplied by the original manufacturer of a product or its successor.

Gilbert. A unit of measurement of magnetomotive force.

Governor. A mechanism which utilizes centrifugal force to automatically maintain the speed of a machine.

Governor brushes. Brushes which make electric contact between the stationary part of the governor mechanism and the collector ring of its rotating part.

Grommet. An insulating washer for protecting wire conductors passing through a hole in a metal panel or terminal box.

Ground. A metallic connection with the earth to establish ground potential. Also, a common return to a point of zero potential.

Ground wire. A conductor connected to a ground rod, water pipe, etc., on one end and attached to a receptable box or appliance on the other.

Growler. A testing device used to check a motor armature.

Half-wave rectifier. A rectifier that changes ac into dc, operating on only one-half of the ac sine wave.

Hazard. Chance; risk; danger.

Head pressure. Pressure which exists in the condensing side of a refrigerating system.

Heat. A form of energy, the addition of which causes substances to rise in temperature; energy associated with random motion of molecules.

Heat fuse. A fuse which collapses at a predetermined temperature to actuate a switch or a valve or to perform some similar function.

Heat loss. Energy loss due to the resistance of a conductor or a coil.

Heat pump. A compression-cycle system used to supply heat to a temperature-controlled space, and which can also be used to remove heat from the same space.

Heat sensor. A thermal resistance unit wherein the temperature changes the resistance (a thermal resistance unit).

Heat sink. A mass of metal attached to a component to draw heat away and assist in dissipating the heat to ambient air or material.

Heater cord. Insulated stranded wire especially manufactured for use on heating appliances.

Heater plug. A heating appliance terminal plug.

Heating element. A resistance wire or ribbon which, when energized, converts electric energy into heat.

Heating unit. A heating element assembled with all its appurtenances.

Helical gear. A gear whose teeth are not at right angles to its tread.

Henry. The basic unit of inductance.

Hermetic motor. A compressor drive motor sealed within the same casing as the compressor.

Hermetic system. A refrigeration system which has a compressor driven by a motor contained in the compressor dome or housing.

Hermetically sealed mechanism. An airtight mechanism; it is usually not designed for servicing in the field.

Hertz. A unit of frequency equal to one cycle per second. Same as *voltage frequency*.

Hi-pot. A test for shock hazard. Abbreviation for high-voltage (high-potential) insulation test. Normally the test voltage is 1,000 V plus twice the operating voltage of the part being tested.

Horsepower. The English unit of power, equal to work done at the rate of 550 ft-lb/s. Equal to 746 W of electric power.

Hot wire. Any ungrounded supply-circuit wire.

Hot-wire relay. A relay which utilizes the movement from the expansion and contraction of a short length of special wire to actuate its switch.

Humidistat. An automatic control device which responds to a predetermined humidity.

Humidity. Moisture; dampness. *Relative humidity* is the ratio of the quantity of vapor present in the air to the greatest amount possible at a given temperature.

Hydrometer. A floating instrument used to measure the specific gravity of a liquid. Specific gravity is the ratio of the weight of any volume of a substance to the weight of an equal volume of another substance used as a standard.

Hysteresis. A lagging of the magnetic flux in a magnetic material behind the magnetizing force which is producing it.

Ice ejector. A machine which ejects ice from an ice tray.

Idler pulley. A pulley which is not keyed either to a driving member or to a driven member.

Ignitor (automatic spark). An electrical or mechanical means of controlling the starting of a controlled flame.

Immersion. The act of putting an object into a liquid so that it is completely covered by the liquid.

Impedance. The total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance.

Impeller. In dishwashers, the part, having spiral blades like those of a screw propeller, which drives the water upward to produce the washing and rinsing actions. Also, in disposers, one of two or more retractable ham-

mers in the flywheel which serve as the rotating shredding element. And, in centrifugal pumps, the revolving fanlike part, the surfaces of whose blades are parallel to the shaft.

In-phase. Applied to the condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same instant.

Increment. One small addition, as to a time cycle.

Index pawl. A movable finger or pin in one subassembly which will latch into any one of several slots or holes in a detent to lock the mechanism in a certain radial position.

Indexing member. That part of a mechanical coupling and/or its shaft end which locks each to the other in a certain radial position so that any movement of one is immediately conveyed to the other.

Induced current. The current flow caused by an induced voltage.

Induced voltage. The voltage induced in a conductor or coil as it moves through a magnetic field.

Inductance. The property of a circuit which tends to oppose a change in the existing current.

Induction. The act or process of producing voltage by the relative motion of a magnetic field across a conductor.

Induction motor. An ac motor with field windings energized by out-of-phase currents. A rotating field is established. The rotor has no electric connections but receives its energy by the transformer action of the field winding. The motor torque is provided by the induced rotor current and the rotating field.

Inductive load. The load on a source of alternating current which will cause the current to lag the voltage.

Inductive reactance. The opposition to the flow of alternating or pulsating current caused by the inductance of a circuit. It is measured in ohms.

Infinite-control switch. A switch which affords virtually unlimited variations of heat intensity between HIGH and OFF by periodically interrupting the power supply to the heater.

Infrared lamp. An electrical device which emits infrared rays, which are invisible rays just beyond red in the visible spectrum.

Inhibitor. A substance added to oil, water, gas, etc., to prevent unwanted action such as rusting, foaming, etc.

Insoluble. Cannot be dissolved.

Insulation. A material for covering wires or components to prevent short circuits and shock hazards. It must be a poor conductor with a high resistance to current flow.

Interlocking device. A mechanism interposed between control elements which forbids the movement of the responding of one control until the other has been properly set for safety or for other reasons.

Intermittent. Starting and stopping again at different times.

Intermittent cycle. A cycle which repeats itself at different intervals.

Inversely. Inverted or reversed in position or relationship.

Ion. An atom which has lost an electron and has a negative charge or has gained an electron, giving it a positive charge.

Ion exchange. Ion exchange occurs when one ion or group of ions replaces another ion or group of ions in a solution.

IR drop. An electrical term indicating the loss in a circuit expressed in amperes × resistance ($I \times R$), or voltage drop.

Isolate. To set apart from others; to place alone; to separate.

Jackscrew. A screw whose purpose is to convert and multiply the effort expended in turning it and to exert this force in a straight line.

Joule. A unit of energy or work. 1 J of energy is liberated by 1 A flowing for 1 s through a resistance of 1 Ω.

Jumper. A length of wire or a conductor used to make temporary connections such as a bypass around a switching component.

Junction box. A metal box where two or

more wire connections may be made and protected.

Jute or twine fillers. The reinforcing strands in an appliance cord.

Kilo. A prefix meaning 1,000.

Kilowatthour. 1,000 W/h. A unit of measurement usually used by power utilities for basing power-usage pricing.

Lacquer. A protective coating or finish which dries to form a film by evaporation of a volatile constituent.

Ladder diagram. A schematic diagram where all components are in a ladder form (one component after another in an up and down picture).

Lag. The amount one electric pulse is behind another in time; expressed in degrees.

Laminated core. A core built up from thin sheets of metal and used in transformers and relays.

Latent heat. Heat energy absorbed in the process of changing the form of a substance (melting, vaporization, fusion) without a change in temperature or pressure. Same as *sublimation.*

Lead. The opposite of *lag.* Also, a wire or connection.

Leaf springs. A suspension spring made of several pieces of flat steel.

Leakage. The flow of current through or over a high resistance or insulating material.

Leveler. A material, generally a paint of some type, used to create a "level" surface. Also a device used to make an appliance level.

Liming up. An expression used to indicate a building up of lime deposits, resulting from the use of hard water.

Limit control. A control used to open or close electric circuits as temperature or pressure limits are reached.

Line. An electric conductor, usually a wire or cable.

Line of force. A line in an electric or magnetic field that shows the direction of the force.

Linear. In a straight line.

Lint. Fine bits of thread, ravelings, or fluff from cloth or yarn.

Liquid absorbent. A chemical in liquid form which has the property to "take on" or absorb moisture.

Liter. Metric unit of volume which equals 61.03 in^3.

Live test. A test in which an appliance is subjected to the same or nearly the same kind of use it would get in actual operation.

Load. The power that is being delivered by any power-producing device. The equipment that uses the power from the power-producing device.

Load-balancing switch. A switch served by a 115/230-V three-wire supply and so designed that it will utilize to the greatest extent possible the higher voltage in order to minimize unbalanced loading of the three-wire system.

Loaded circuit. A circuit to which a power-consuming device is connected.

Loss. A circuit using low-voltage current to operate relay coils, which in turn control switches for operating higher-voltage circuits.

Lubrication. The act of making slippery or smooth in order to reduce friction. This is usually done with an oil or grease.

Magnetic circuit. The complete path of magnetic lines of force.

Magnetic field. The space in which a magnetic force exists.

Magnetic flux. The total number of lines of force issuing from a pole of a magnet.

Magnetic gasket. A sealing material which adheres due to small magnets inserted in the gasket.

Magnetize. To convert a material into a magnet by causing the molecules to rearrange.

Magneto. A generator which produces alternating current and has a permanent magnet as its field.

Magnetron. A vacuum tube in which the flow of electrons from the heated cathode to the anode is controlled by a magnetic field, externally applied and perpendicular to the electric field, and by which the electrons are

propelled. It is used to produce very short radio waves.

Manifold. A device used for refrigeration service which includes valves and gauges to allow connection to a refrigeration system for the purpose of analyzing its operation.

Manometer. An instrument for measuring the pressure of gases or vapors.

Master switch. A switch which controls the operation of, or the circuit to, several other switches.

Matter. The physical substances of which an object is composed.

Maximum value. The peak value of a sine wave in either direction.

Maxwell. A single line of magnetic flux.

Mean effective pressure. The average pressure on a surface when a changing pressure condition exists.

Mechanical cycle. A cycle which is a repetitive series of mechanical events.

Megger. A test instrument used to measure insulation resistance and other high resistances. It is a portable, hand-operated dc generator used as an ohmmeter.

Melting point. Temperature, at atmospheric pressure, at which a substance will melt.

Mercury bulb. An electric circuit switch which uses a small quantity of mercury in a sealed glass tube to make or break electric contact with terminals within the tube.

Mercury switch. An electric switch made by placing a large globule of mercury in a glass tube having electrodes arranged in such a way that tilting the tube will cause the mercury to make or break the circuit.

Meter. An instrument or device for measuring quantities of electricity.

Metric system. A decimal system of measures and weights, based on the meter and gram. The length of one meter is 39.37 in.

Mho. The unit of measurement of conductance.

Micro. A prefix meaning one millionth.

Micro switch. A switch of relatively small dimensions having an incredibly short and easy movement in proportion to its capacity.

Micromicro. The prefix meaning one millionth of one millionth.

Milli. A prefix meaning one thousandth.

Milliammeter. An ammeter that measures current in thousandths of an ampere.

Minute timer. One designed for timing periods of 1 h or less.

Modulator. A device that regulates.

Molecule. The smallest division of matter. If subdivided further, the matter loses its identity.

Motor. The opposite of a generator. It converts electric energy to mechanical energy.

Motor burnout. A condition in which the insulation of an electric motor has deteriorated and the copper winding has melted because of overheating.

Motor control. A device to start and/or stop a motor at certain temperatures or pressures.

Motor generator. A motor and a generator with a common shaft used to convert line voltages to other voltages or frequencies.

Motor starters. High-capacity electric switches, usually operated by electromagnets.

Mullion element. A heating element installed in the small bars of a refrigerator to prevent frost buildup.

Mutual induction. A circuit property existing when the relative position of two inductors causes the magnet lines of force from one to link with the turns of the other.

Negative charge. The electric charge carried by a body which has an excess of electrons.

Neon. An inert gas.

Neon tester. A tester which can be used on a wide range of voltages and is capable of disclosing minute current leaks.

Neutral. Neither positive nor negative.

Neutral conductor. The grounded third wire in a three-wire system. It will have a 120-V potential with either hot wire in a 240-V system.

Neutral wire. The common wire, usually grounded, of the popular 115/230-V three-wire single-phase ac system; also the common in other multiwire or multiphase systems.

Neutron. A particle having the weight of a

proton but carrying no electric charge. It is located in the nucleus of an atom.

Nichrome. An alloy of nickel and chromium. A high-resistance wire used for heating elements.

Nominal size tubing. Tubing which has an inside diameter the same as that of iron pipe of the same stated size.

Noncondensable gas. Gas which does not change into a liquid at operating temperatures and pressures.

Normally closed. Refers to switch contacts if normally closed when the switch is in a nonactivated state. Opposite of *normally open.*

Nucleus. The central part of an atom; it is mainly comprised of protons and neutrons. It is the part of the atom that has the most mass.

Null. Zero.

Off cycle. That part of a refrigeration cycle when the system is not operating.

Ohm. The unit of electric resistance.

Ohmmeter. An instrument for directly measuring resistance in ohms.

Oil capacitor. A capacitor with oil-impregnated paper as a dielectric.

Oil rings. Expanding rings mounted in grooves on the piston; designed to prevent oil from moving into the compression chamber.

Oil seal. The subassembly which prevents oil from leaking along a shaft which emerges from a gear box below the oil level.

Oil separator. A device used to remove oil from gaseous refrigerant.

One-way clutch. A clutch which will transmit motion from one of its elements to the other, but only when driven in one specific direction.

One-way coupling. A coupling which will slip if driven in the direction opposite to that for which it was designed.

Open circuit. An interrupted electric circuit in which the flow of electricity has stopped.

Orifice. An accurate-size opening for controlling fluid flow.

Oscillation. Flucutation, instability; a single swing of a swinging object. The variation between maximum and minimum values, as in alternating current.

Oven element. A certain resistance used to warm and cook foods in an enclosed unit.

Overload. A load greater than the load for which the system or mechanism was intended.

Overload protector. A device, either temperature-, pressure-, or current-operated, which will stop the operation of a unit if a dangerous condition arises.

Overload switch. In washing machines, an ON-OFF and manual reset switch which features an electromagnetic tripping mechanism for overload protection.

Overshooting. Slight overheating on a thermostat's first automatic cutoff.

Oxidation. The union of oxygen with another substance. It generally causes an increase in electric resistance.

Ozone. A gaseous form of oxygen usually obtained by the silent discharge of electricity in oxygen or air.

Panel box. A fuse and switch box from which branch circuits emanate.

Paper capacitor. A capacitor in which the foil plates are separated by waxed paper.

Parallel circuit. A circuit containing two or more parallel paths for electrons supplied by a common source.

Parallel connection. A manner of connecting a group of devices in which one pole of each is connected to one common wire and the other pole of each is connected to a second common wire. Opposed to series connection.

Partial pressures. A condition in which two or more gases occupy a space and each one creates part of the total pressure.

Peak. The highest or maximum value of a sine wave reached during a cycle.

Percolate. To drain or ooze through a porous substance; to pass a liquid gradually through a porous substance; to filter, as water through soil.

Permalloy. An alloy of nickel and iron having an abnormally high magnetic permeability.

Permanent magnet. Hardened steel or special alloy which retain the magnetic effect after a magnetizing force has been removed.

Permeability. A measure of the ease with which magnetic lines of force can flow through a material as compared with the ease with which magnetic lines can flow through air.

Phase. When two sine waves pass through their zero positions at the same time, they are in phase.

Phase angle. The angular difference between the two vectors of two sine waves.

Phase difference. The time in degrees by which one sine wave leads or lags another.

Photoelectricity. A reaction in which an electron flow is generated by light waves.

Pigtail. A flexible cable extending from a component or appliance for ease of connection.

Pigtail tester. A weatherproof lamp socket having permanently connected leads about 6 in long and a lamp to suit the voltage of the circuit to be tested.

Pilot lamp. A lamp to indicate whether a circuit is energized.

Pinion. The small gear in a set, either helical or spur.

Piston. A close-fitting part which moves up and down in a cyclinder.

Pivot. A point, shaft, etc., on which something turns; to turn as if mounted on such a point.

Planetary-gear drive. A train of gears, one (or more) of which will travel with its axis around the circumference of another.

Polarity. The character of having magnetic poles, or electric charges.

Polarized circuit. The use of a white or marked wire for the ground side of a circuit.

Polarized plug. A plug so designed as to assure matching of its poles with those of the receptacle to which it is connected.

Pole. The section of a magnet where the flux lines are concentrated; also where they enter and leave the magnet. An electrode of a battery.

Polyphase. A circuit that utilizes more than one phase of alternating current.

Positive charge. The electric charge carried by a body which has become deficient in electrons.

Potential. The amount of charge held by a body as compared to another point or body. Usually measured in volts.

Potentiometer. A variable voltage divider, a resistor which has a contact arm so that any portion of the potential applied between its ends may be selected.

Power. The rate of doing work or the rate of expending energy. The unit of electric power is the watt.

Power element. The sensitive element of a temperature-operated control.

Power factor. The ratio of the actual power of an alternating or pulsating current as measured by a wattmeter, to the apparent power, as indicated by ammeter and voltmeter readings. The power factor of an inductor, capacitor, or insulator is an expression of their losses.

Power loss. Loss in a circuit due to resistance of conductors.

Pressure. An energy impact on a unit area; force or thrust exerted on a surface.

Pressure drop. The pressure difference at two ends of a circuit, or part of a circuit, between the two sides of a filter, or between the high side and low side in a refrigerator mechanism.

Pressure gauge. A tool that measures pressure in pounds per square inch.

Pressure-operated altitude valve. A device which maintains a constant low-side pressure independent of altitude of operation.

Pressure plate. The plate immediately above the heating unit in an iron.

Pressure switch. In washing machines, a switch which is actuated by a diaphragm or similar device and responds to the force exerted by a predetermined quantity of water.

Primary. The incoming side of a transformer. The side from which the voltage or current is being changed to a different value by the transformer.

Prime mover. The source of mechanical power used to drive the motor of a generator.

Process tube. A length of tubing fastened to the hermetic-unit dome, used for servicing the unit.

Prods. Solid wire points, with insulated handles, which are spliced to flexible testing leads. Same as *testing points.*

Propane. Volatile hydrocarbon used as a fuel and as a refrigerant.

Proton. A positively charged particle in the nucleus of an atom.

Psychrometer or wet-bulb hygrometer. An instrument used to measure relative humidity in the air.

Pulser timer. A device used in major appliances that starts and stops different operations with a throbbing effect.

Purging. Releasing compressed gas to the atmosphere through some part or parts for the purpose of removing contaminants from that part or parts.

Purging hose. A hose through which gas, air, water, or other liquid is forced to cleanse away unwanted matter.

Pyrolysis. Chemical change brought about by the action of heat.

Pyrometer. A thermometer for measuring unusually high temperatures.

Rackbar. A bar having gear teeth on one side over a part of its length and a bearing on its other end.

Radiation. Transfer of heat through space by rays or waves.

Range. Pressure or temperature settings of a control, within limits. Also a home cooking unit.

Range cord. A flexible, three-wire, insulated cord for connecting an electric range to a wall receptacle.

Ratio. The value obtained by dividing one number by another, indicating their relative proportions.

Reactance. The opposition offered to the flow of an alternâting current by the inductance, capacitance, or both, in any circuit.

Reactive load. A load consisting of inductive reactance which causes the current to lag the applied voltage.

Receptacle. A box-mounted female connector into which the service-cord plug may be inserted.

Reciprocating. Action in which the motion is back and forth in a straight line.

Rectifiers. Devices designed intentionally to limit the flow of current or to provide a voltage drop. Also devices used to change alternating current to direct current. These may be vacuum tubes, semiconductors such as germanium and silicon, and dry-disk rectifiers such as those made of selenium and copper oxide.

Reed valve. A thin, flat, tempered steel plate fastened at one end.

Refrigerant. A substance used in a refrigerating mechanism to absorb heat in the evaporator coil by a change of state from a liquid to a gas, and to release its heat in a condenser as the substance returns from the gaseous state back to a liquid state.

Refrigerant control. The device which regulates the flow of refrigerant between one part of a system and another.

Regenerate. To bring into existence again; reestablish; to cause to be completely reformed or improved; to renew; restore; to grow (a part) anew; to replace a part lost.

Relative humidity. The ratio of the amount of water vapor present in the air to the greatest amount possible at the same temperature.

Relay. An electromechanical switching device that can be used as a remote control.

Relief valve. A safety device designed to open and relieve pressure before a dangerous condition is reached.

Reluctance. A measure of the opposition that a material offers to magnetic lines of force.

Residual. A remainder; a remaining force, as in magnetism; left over.

Resin beads. A sandlike plastic material used in water softeners.

Resistance. The opposition to the flow of

current caused by the nature and physical dimensions of a conductor.

Resistor. A circuit element whose chief characteristic is resistance; it is used to oppose the flow of current.

Resonance. The state of adjustment of an electric circuit that permits the greatest flow of current of a particular frequency.

Restrict. To limit, confine, keep within bounds.

Restrictors. The tapes, links, or the like, used in conjunction with an automatic washer's mechanism supports, which limit free bodily movement of a spring-suspended mechanism.

Retentivity. The measure of the ability of a material to hold its magnetism.

Reversing switch. A switch which will reverse a motor's direction of rotation. In split-phase motors, reversing is accomplished by transposing the starting-winding leads.

Rheostat. A variable resistor, or group of resistors, equipped with a selector control.

Rotor. The rotating part of a generator or motor.

Safety control. A device which will stop a unit if unsafe pressures and/or temperatures are reached.

Safety plug. A device which will release the contents of a container when normal pressure conditions have been exceeded and before rupture pressures are reached.

Safety switch. An externally operated, fused switch which protects and controls a special-purpose branch circuit in the house wiring and is situated at the circuit's point of origin.

Safety thermostat. A thermostat that limits the temperature of an appliance.

Saturation. The condition existing in any circuit when an increase in the driving signal produces no further change in the resultant effect.

Schematic. A line drawing of an electric circuit showing components and connections in the form of symbols.

Score. To make a scratch mark or line to show a starting point or cutting line.

Screw extractor. A tool used to remove broken bolts, screws, etc., from holes.

Screw-on wire connector. A thimble-shaped nut with a tapering internal thread which may be screwed onto the straight bared ends of two or more wires which have been laid side by side to form a compact, insulated, rat-tail splice.

Seals. A rubber rim used in washing machines to keep the water or fluids from getting into the motor or transmission of the machine.

Secondary. The outgoing side of a transformer where the new value of the voltage or current is available.

Secondary controls. Controls which must respond to complete a function but which do not originate it.

Sector. A triangular-shaped gear.

Sediment. Any matter that settles to the bottom of a liquid, such as soil in still water.

Seize. When two parts rub together so that they get hot and force the lubricant out of the area they "gall" and finally seize or stick together.

Selector switch. A switch which will connect any one of several circuits to a single power supply but not simultaneously.

Self-induction. The process by which a circuit induces an emf into itself by its own magnetic field.

Self-oiling bearing. A bearing which is impregnated with lubricant.

Semiconductor. A conductor which has a resistance value in between that of a good conductor and that of an insulator.

Sensible heat. Heat which causes a change in the temperature of a substance.

Sensor. A material or device which goes through a physical change or an electronic-characteristic change as the ambient conditions change.

Series circuit. A circuit which contains only one possible path for electrons through the circuit. This path may pass through more than one component or terminal.

Series connection. A manner of connecting a group of devices in which one pole of one

device is connected to one pole of another, leaving one pole on each end of the series for connecting to a supply or to another circuit.

Series tester. A device for the preliminary testing of appliances in which a lamp and/or other resistance(s) are interposed in one pole of the supply circuit.

Series-type commutator motor. A motor whose field coils are connected in series with its commutator brushes.

Series-wound. A motor or generator in which the armature is wired in series with the field winding.

Serrated. Having sawlike teeth or notches along the edge.

Service drop. The lines connecting the power company's main lines to the home.

Service entrance. The riser, meter installation, and fuse box.

Service valve. A device to be attached to a system which provides an opening for gauges and/or charging lines. Also provides a means of shutting off or opening the gauge and charging ports, and controlling refrigerant flow in the system.

Servo. A device used to convert a small movement into a greater movement or force.

Servomechanism. A closed-loop system that produces a force to position an object in accordance with the information that originates at the input.

Shaded-pole motor. A motor having each of its field poles split to accommodate a short-circuiting copper strap. The copper strap is wrapped around one of the split sections. It is called a shading coil. This coil produces a sweeping movement of the magnetic field across the pole face for starting.

Shaft. A bar which sends (relays) motion to or supports a mechanical part of an engine.

Sheath. The protective jacket on a cable or wire.

Sheathed element. An element which is enclosed in a sealed metallic casing.

Shim. A thin washer, precisely sized, used to eliminate end motion between the shoulder on a shaft and its bearing boss.

Short circuit. A direct circuit across the electric source providing a zero-resistance path for the current. The dangerously high current flow may cause a fire.

Short-cycling. Condition in which a unit starts and stops more frequently than it does in normal operation.

Silica gel. A chemical compound used as a drier (an agent which has the ability to absorb moisture). When heated, moisture is released and the compound may be reused.

Silver brazing. A brazing process in which the brazing alloy contains some silver as part of the joining alloy.

Sine wave. The waveform of a single-frequency alternating current. A wave whose displacement is the sine of an angle proportional to time.

Single-phase motor. A motor which operates on single-phase alternating current.

Single-pole, double-throw switch. An electric switch with one blade and two contact points.

Siphon break. An air gap between a hose and a drain.

Sleeve. A tube or tubelike part fitting around another part.

Slinger. A loose-fitting ring around the shaft which turns and throws aside any leaking liquid.

Slip. The difference in speed between the rotor and the stator field as compared to the synchronous speed of a motor.

Snap-ring pliers. Pliers whose jaws, shaped to go between and receive the ends of a snap ring, open outward when the handles are squeezed.

Snifter valve. A valve on the inlet side of a pump which will permit air to enter the system.

Snubber. A device used to limit the travel of some part, checking or stopping it sharply.

Soldering. Joining two metals by adhesion of a low-melting-temperature metal (at less than 800°F).

Solenoid. An electromagnetic coil that contains a movable plunger.

Solvent. Something used for dissolving something else.

Spark ignitor. An electrical or mechanical means of starting a controlled flame, as in an oil burner.

Specific gravity. The ratio between the density of a substance and that of pure water at a given temperature.

Specific heat. Ratio of the quantity of heat required to raise the temperature of a body one degree to that required to raise the temperature of an equal mass of water one degree.

Spin. To whirl rapidly in one direction, as in an automatic washer.

Spit. A pointed shaft.

Split-phase motor. A single-phase induction motor. It develops its starting torque by a phase difference between the starting windings and the running windings of the field.

Spool clutch. A clutch having a spool-like groove to receive the shifter shoe or finger.

Spring-loaded pawl clutch. A clutch having a pawl which is held in one position or the other (engaged or disengaged) by a spring.

Spring-motored. Driven by a spring, as a windup clock.

Spur gear. A gear whose teeth are at right angles to its tread.

Squirrel-cage rotor. The rotor of an induction motor, made of bars placed in slots in the core and all joined together at the ends.

Standard atmosphere. Condition when air is at a pressure of 14.7 lb/in^2 at 68°F.

Standpipe. Used with washing machines to accept the drain hose when there is no tub.

Starter. The automatic switch used in a fluorescent light.

Starting relay. An electrical device which connects and/or disconnects the starting winding of an electric motor.

Starting winding. The winding in an electric motor used only during the brief period when the motor is starting.

Static electricity. Atmospheric electricity. Electricity without motion as compared with electric current, which is electricity in motion.

Stator. The stationary field coils of a generator or a motor.

Step down. To reduce from a higher to a lower voltage, as in a step-down transformer.

Step up. To increase to a high voltage by use of a transformer.

Strain relief. A device which firmly attaches a power cord to a machine.

Strainer. A device, such as a screen or filter, used to retain solid particles while liquid passes through.

Stuffing box. The cavity surrounding a shaft where it emerges from a bearing, into which packing is compressed by a gland and a nut to prevent leaking of oil, water, or the like.

Suction line. A tube or pipe used to carry refrigerant gas from the evaporator to the compressor.

Suds lock. Condition of a washing machine's water system becoming obstructed by the use of excessive amount of soap or detergent.

Sump. A pit or reservoir serving as a drain for fluids.

Superheat. The temperature of vapor which is above the boiling temperature of its liquid at that pressure. To heat a substance to this temperature.

Surge. Modulating action of a temperature or pressure before it reaches its final value.

Suspension bolt. Bolts used to hold an object from the top to allow movement of the part being held.

Swaging. Enlarging the end of a tube so that the end of another tube of the same size will fit within it.

Sweating. This term is used two different ways in refrigeration work: (1) condensation of moisture from air on a cold surface; (2) method of soldering in which the parts to be joined are first coated with a thin layer of solder.

Switch. A mechanical device for opening or closing a circuit.

Synchro system. An electric system that gives remote indications or control by means of self-synchronizing motors.

Synchronous. Having the same period of frequency.

Synchronous speed. The speed of the rotating magnetic field set up by the stator of an induction motor. In a synchronous motor the rotor locks into step with the rotating magnetic field.

Synchroscope. An instrument used to indicate a difference in frequency between two ac sources.

Tachometer. An instrument for indicating revolutions per minute.

Tap. A connection made to a coil at a point other than its terminal.

Tapped field. Motor field coils to which several leads have been tapped at various points on the winding during manufacture for connecting to a selector switch to provide speed control by varying the resistance in the field.

Temperature. Degrees of hotness or coldness as measured by a thermometer.

Temperature control. An automatic switch, valve, or the like, which responds to changes in temperature.

Temperature-limit switch. A switch which will interrupt a circuit at a predetermined temperature.

Temperature-relief valve. A valve which will open at a predetermined temperature.

Terminal. A point of electric connection.

Tertiary winding. A third winding on a transformer or magnetic amplifier that is used as a second control winding.

Thermistor. A resistor that is used to compensate for temperature variations in a circuit.

Thermocouple. A junction of two dissimilar metals that produces a voltage when heated. Also an instrument comprised of two wires of dissimilar metals united at one end (the thermal junction) and connected to a temperature meter at the other. A weak electric current is generated in the wires when heat is applied to the thermal junction, and this energy is utilized to actuate the meter. Since the pressure of this current varies proportionately with the temperature at the junction, the meter registers rather accurately the temperature of an appliance under test when the junction is placed properly.

Thermometer. A device used for measuring temperatures.

Thermostat. An automatic control which responds to a predetermined temperature, which can be altered, in some designs, by moving a selector dial.

Three-heat switch. One with four positions, HIGH, MEDIUM, LOW, and OFF, used in combination with a group of heating elements to provide three heats by various connecting schemes between the supply circuit and the elements.

Throttling. Expansion of gas through an orifice, or controlled opening, without the gas performing any work in the expansion process.

Thrust-adjusting screw. A screw which is threaded into a blind bearing cavity and whose position can be altered by loosening a check nut to reduce the end play of a shaft.

Timer. A mechanism used to control the on and off times of an electric circuit.

Tin. A trade term, meaning to coat with an extremely thin layer of solder (tin and lead).

Tolerance. Amount of variation or change allowed from a standard accuracy; especially the difference between the allowable maximum and minimum sizes of some mechanical part.

Torque. The turning effort or twist which a shaft sustains when transmitting power.

Transformer. A device composed of two or more coils, linked by magnetic lines of force, used to transfer energy from one circuit to another.

Transmission lines. Any conductor or system of conductors used to carry electric energy from its source to a load.

Transpose polarity. To interchange the connections to a pair of poles.

Tubing. Fluid-carrying pipe which has a thin wall.

Universal motor. A series motor which operates on either alternating or direct current.

Urethane foam. A type of insulation which is foamed in between the inner and outer walls of a refrigerator.

Vacuum. A reduction in pressure below atmospheric pressure.

Vacuum pump. A special high-efficiency compressor used for creating high vacuums for testing or drying purposes.

Valve. A device used for controlling the flow of fluid.

Vapor. A word usually used to denote vaporized refrigerant rather than the word "gas."

Velocity (air). Rate of motion of air in one particular direction in relation to time speed.

Vent. An opening for passage or escape of fluids, smoke, or air.

Vibration dampers. The resilient members in a mechanism's supports which are intended to absorb vibration.

Viscosity. A term used to describe a fluid's resistance to flow.

Volatile liquid. A liquid which evaporates at a low temperature and pressure.

Volt. The unit of electric potential.

Voltage drop. The voltage measured across a resistance. It is equal to the product of the current in amperes times the resistance in ohms.

Voltmeter. An instrument designed to measure a difference in electric potential, in volts.

Water glass. A syruplike, fireproof cement (sodium silicate).

Water level. The surface or height of still water.

Watt. The practical unit of electric power. In direct current, wattage is equal to volts times amperes. In alternating current, true watts are equal to effective volts multiplied by effective amperes, then multiplied by the circuit power factor. 746 W equal one common horsepower.

Wattmeter. A meter used to measure power in an electric circuit, in watts.

Waveform. The shape of a wave found by plotting its instantaneous amplitude values against time.

Waveguide. A waveguide is an electric conductor consisting of a metal tubing used for the conduction or directional transmission of microwaves.

Wavelength. Wavelength is that distance between corresponding points on two successive waves.

Wiring harness. A bundle of individually insulated wires.

Woodruff key. A holding device that is semicircular in shape.

Working voltage. The maximum voltage that can be continuously applied to a capacitor without the danger of arcing between the plates.

Worm and worm gear. The worm, a spiral-like shaft resembling a coarse screw, is usually the driving member; the worm gear (or wheel) is usually the driven member. Considerable power increase and resultant speed reduction are possible with this type of gearing, and quiet operation is typical.

Zip tube. A perforated pipe which conveys a light to a pilot burner, thus aiding in the igniting of a flame heating unit.

Common abbreviations and letter symbols

APPENDIX

B

Term	Abbreviation or symbol
adjustable	adj.
alternating current (noun)	ac (a.c.)
alternating-current (adj.)	ac (a-c)
American Wire Gauge	AWG
ampere	A (amp)
ampere (turn)	A
ampere-hour	Ah
Association of Home Appliance Manufacturers	AHAM
audiofrequency (noun)	AF
automatic	auto.
automatic ice service	AIS

Term	Abreviation or symbol
British thermal unit	Btu
capacitance	C
capacitive reactance	X_c
capacitor	cap.
capacitor start–capacitor run	CSCR
capacitor start–induction run	CSIR
Centigrade	°C
centimeter	cm
circular mil	cmil (cir mil)
common	c
compressor	comp.
conductance	G
continuous	cont.
coulomb	C (Q)
counterelectromotive force	counter-emf (cemf)
cubic feet per minute	ft^3/min (CFM)
current (dc or rms value)	I
current (instantaneous value)	i
current carrying	c.c.
degrees	°
dielectric constant	K, k
difference in potential (dc or rms value)	E
difference in potential (instantaneous value)	e
direct current (noun)	dc (d.c.)
direct-current (adj.)	dc (d-c)
double-pole, double-throw switch	DPDT
dry bulb	DB
electronic air cleaner	EAC
electromotive force	emf
Fahrenheit	°F
filament	fil.
frequency	f
gallons per minute	gal/min (gpm)
gilbert	Gb
gram	g
henry	H (h)
hermetic	herm

Term	Abbreviation or symbol
hertz	Hz
high	hi
horsepower	hp
impedance	Z
inductance	L
inductive reactance	X_L
inside diameter	ID (i.d.)
interlock	intlk.
internal pressure relief	IPR
kilocycle per second	kHz
kilohm	kΩ
kilovolt	kV
kilovoltampere	kVA
kilowatt	kW
kilowatthour	kWh
liquefied petroleum gas	LPG
low	lo
magnetic field intensity	H
magnetomotive force	mmf
magnetron	mag.
maximum	max.
maxwell	Mx
mean effective pressure	mep
mega	M
megacycle per second	MHz
megohm	MΩ
microampere	μA
microfarad	μF (mfd)
microhenry	μH
microvolt	μV
microwatt	μW
milliampere	mA
millihenry	mH (mh)
millimeter	mm
millivolt	mV
milliwatt	mW
minimum	min.
mutual inductance	M
National Electrical Code	NEC
normal	norm.
normally closed	N.C.
normally open	N.O.
ounce (avoirdupois)	oz

Term	Abbreviation or symbol
outside diameter	OD (o.d.)
overload	o.l.
permanent capacitor	pc
permanent split capacitor	PSC
picofarad	pF
pint	pt
pounds per square inch	lb/in^2 (psi)
power	*P*
pressure-operated altitude value	poav
quart	qt
radio frequencies	rf
rectifier	rect.
repulsion-induction	RI
resistance	*R*
resistance start–induction run	RSIR
revolutions per minute	r/min (rpm)
revolutions per second	r/s
room air conditioner	RAC
root mean square	rms
silicon controlled rectifier	SCR
single-pole, double-throw switch	SPDT
single-pole, normally closed	SPNC
single-pole, normally open	SPNO
single-pole, single-throw switch	SPST
Society of Automotive Engineers	SAE
split-phase induction	SPI
switch	sw
temperature	temp.
temperature differential	TD
temperature humidity index	THI
terminal board	term. bd.
therm	thm.
thermo protector	therm. prot.
thermostat	thermo.
time	*t*
torque	*T*
transformer	xfmr.
transistor	PNP
ultrahigh frequences	uhf
Underwriters Laboratories Inc.	UL
unijunction transistor	UJT
volt	V
voltampere	VA
volt-ohm-milliammeter	vom
watt	W
wet bulb	WB

For fast and easy servicing, most manufacturers use a component-terminal-marking and wiring-color-coding system. These terminal markings appear in the wiring diagram as well as the wiring color-coding symbols. The following table lists the color coding most generally used:

Terminal color code	Harness lead color
BK	Black
BR	Brown
BR-R	Brown with red tracer
BU	Blue
BU-G	Blue with green tracer
BU-R	Blue with red tracer
BU-Y	Blue with yellow tracer
G	Green
G-BK	Green with black tracer
G-W	Green with white tracer
GY	Gray
GY-P	Gray with pink tracer
LBU	Light blue
OR	Orange
O-BK	Orange with black tracer
P	Pink
P-G	Pink with green tracer

Terminal color code	Harness lead color
P-W	Pink with white tracer
R	Red
R-G	Red with green tracer
R-Y	Red with yellow tracer
T	Tan
T-G	Tan with green tracer
V	Violet
V-Y	Violet with yellow tracer
W	White
W-G	White with green tracer
Y	Yellow
Y-G	Yellow with green tracer

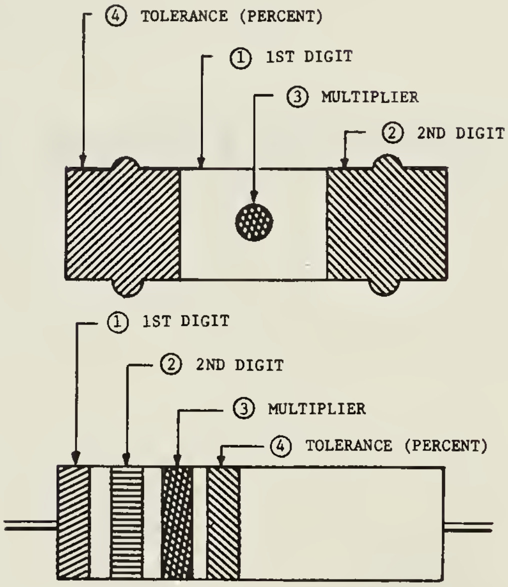


Figure B-1.

The resistor color code enables you to tell at a glance (with a little practice) the value of a coded resistor. This is a uniform system for marking small carbon resistors with three or four bands painted on the body of the resistor. The color code and its numerical values are as follows:

Color of band	Numerical value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9
Gold	±5%
Silver	±10%
No band	±20%

To identify the value of a resistor, the bands should be read starting at the end and going toward the center of the resistor:

1. The first band indicates the first significant number.
2. The second band indicates the second significant number.
3. The third band indicates the number of zeros to be affixed after the first two digits.
4. The fourth band indicates the percentage of tolerance in the resistor value. A gold band indicates a tolerance of 5 percent; a silver band indicates a tolerance of 10 percent; and no fourth band at all indicates a tolerance of 20 percent.

Formulas of importance

APPENDIX

C

Ohm's Law (dc)

$$I = \frac{E}{R} \qquad E = I \times R \qquad R = \frac{E}{I}$$

where I = current, in amperes
E = potential, in volts
R = resistance, in ohms

Dc Power

The power expended in a load resistance when a current is caused to flow by a potential can be determined by the following formulas:

$$P = E \times I \qquad P = \frac{E^2}{R} \qquad P = I^2 \times R$$

where P = power, in watts
E = potential, in volts
I = current, in amperes
R = resistance, in ohms

Resistance

1. In series:

$$R_T = R_1 + R_2 + R_3 + \cdots + R_N$$

where R_T is the total resistance of the circuit, and N is the number of resistors or loads in the circuit.

2. In parallel:

$$R_T = \frac{1}{1/R_1 + 1/R_2 + 1/R_3 + \cdots + 1/R_N}$$

3. Two resistors in parallel:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

Capacitance

1. In series:

$$C_T = \frac{1}{1/C_1 + 1/C_2 + 1/C_3 + \cdots + 1/C_N}$$

where C_T is the total capacitance of the circuit, and N is the number of capacitors in the circuit.

2. In parallel:

$$C_T = C_1 + C_2 + C_3 + \cdots + C_N$$

Inductance

1. In series:

$$L_T = L_1 + L_2 + L_3 + \cdots + L_N$$

where L_T is the total inductance in the circuit, and N is the number of inductors in the circuit.

2. In parallel:

$$L_N = \frac{1}{1/L_1 + 1/L_2 + 1/L_3 + \cdots + 1/L_N}$$

Frequency

Fundamental formula:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where f = frequency, in cycles per second
L = inductance, in henrys
C = capacitance, in farads
$\pi = 3.14159 \ldots$

Reactance

1. Inductive reactance:

$$X_L = 2\pi f L$$

where X_L = inductive reactance, in ohms
f = frequency, in cycles per second
L = inductance, in henrys

2. Capactive reactance:

$$X_c = \frac{1}{2\pi f C}$$

where X_c = capacitive reactance, in ohms
f = frequency, in cycles per second
C = capacitance, in farads

Ohm's Law (ac)

$$I = \frac{E}{Z} \quad \text{or} \quad I = \frac{E}{R^2 + (2\pi f L - 1/2\pi f C)^2}$$

where I = current, in amperes
E = potential, in volts
Z = impedance, in ohms

Comparison of Units in Electric and Magnetic Circuits

	Electric circuit	Magnetic circuit
Force	Volt, E, or emf	Gilberts, F, or mmf
Flow	Ampere, I	Flux, $\varnothing$, in maxwells (Mx)
Opposition	Ohms, R	Reluctance, R
Law	Ohm's law, $I = E/R$	Rowland's law, $\varnothing = F/R$
Intensity of force	Volts per centimeter of length	$H = 1.2571N/L$, gilberts per centimeter of length
Density	Current density—for example, amperes per square centimeter	Flux density—for example, lines per square centimeter, or gausses

Current, Power, and Horsepower Calculations

The following formulas are for computing current, power, and horsepower with different types of common power-distribution systems.

		Alternating current		
Required	Direct current	Single-phase	Two-phase, four-wire	Three-phase
Current when horsepower is known	$\frac{hp \times 746}{E \times eff}$	$\frac{hp \times 746}{E \times eff \times PF}$	$\frac{hp \times 746}{2 \times E \times eff \times PF}$	$\frac{hp \times 746}{1.73 \times E \times eff \times PF}$
Current when kilowatts are known	$\frac{kW \times 1{,}000}{E}$	$\frac{kW \times 1{,}000}{E \times PF}$	$\frac{kW \times 1{,}000}{2 \times E \times PF}$	$\frac{kW \times 1{,}000}{1.73 \times E \times PF}$
Current when kVA is known		$\frac{kVA \times 1{,}000}{E}$	$\frac{kVA \times 1{,}000}{2 \times E}$	$\frac{kVA \times 1{,}000}{1.73 \times E}$
Power in kilowatts	$\frac{I \times E}{1{,}000}$	$\frac{I \times E \times PF}{1{,}000}$	$\frac{2 \times I \times E \times PF}{1{,}000}$	$\frac{1.73 \times I \times E \times PF}{1{,}000}$
Power in kVA		$\frac{I \times E}{1{,}000}$	$\frac{2 \times I \times E}{1{,}000}$	$\frac{1.73 \times I \times E}{1{,}000}$
Horsepower output of a motor	$\frac{I \times E \times eff}{746}$	$\frac{I \times E \times eff \times PF}{746}$	$\frac{2 \times I \times E \times eff \times PF}{746}$	$\frac{1.73 \times I \times E \times eff \times PF}{746}$

I = current, in amperes
E = potential, in volts
eff = efficiency (expressed as a decimal)
hp = horsepower
PF = power factor
kW = power in kilowatts
kVA = power in kilovoltamperes

Power consumption of home appliances

APPENDIX

D

Electrical Appliances

Appliance	Approximate kilowatthours per month	Remarks
Blanket (automatic)	15	8 h/day (used 7 months)
Clock	$1\frac{1}{2}$	
Coffee maker	15	25 h/month
Dishwasher	25	$1\frac{1}{2}$ washings per day
Dryer (clothes)	50	10 h/month (family of 4)

Electrical Appliances (*cont'd*)

Appliance	Approximate kilowatthours per month	Remarks
Fan (10-in)	1	25 h/month
Food freezer	40	8 ft^3
Garbage disposal unit	$\frac{3}{4}$	4 min/day
Iron	6	12 h/month
Ironer	10	10 h/month (family of 4)
Lighting	65	
Mixer	$\frac{3}{4}$	5 h/month
Oil furnace (not including) circulator fan)	30	(200–500 kWh/year)
Range	90	(Family of 4)
Refrigerator	22	8 ft^3
Roaster	12	16 h/month
Sandwich grill	4	5 h/month
Sewing machine	1	
Toaster	3	3 h/month
Vacuum cleaner (upright)	$2\frac{1}{4}$	6 h/month
Vacuum cleaner (tank)	$3\frac{1}{4}$	6 h/month
Washer (wringer-type)	2	12 h/month (family of 4)
Washer (automatic)	3	12 h/month (family of 4)
Water heater	350	(Family of 4)

Gas Appliances

Appliance	Input Btu/h (approximate)
Clothes dryer, domestic	35,000
Range (free-standing, domestic)	65,000
Built-in oven or broiler unit domestic	25,000
Built-in top unit (domestic)	40,000
Water heater, automatic storage (50-gal tank)	55,000
Water heater, automatic instantaneous,	
2 gal/min	142,800
4 gal/min	285,000
6 gal/min	428,400
Water heater, domestic, circulating	35,000
Refrigerator	3,000

Glossary of symbols

APPENDIX

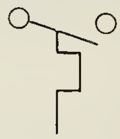
E

The symbols used in this book and illustrated in a glossary form here conform to the graphic symbols and electronic diagrams approved by the American National Standards Institute. [Although the name of the organization approving the symbols has changed from the American Standards Association to the U.S.A. Standards Institute to the American National Standards Institute (ANSI), the approved symbols have remained basically the same.] But the service technician who works on many brands of appliances must be able to interpret a variety of wiring symbols. Often a symbol is the "brainchild" of an engineer and does not conform to any standard. Here are ANSI symbols of interest to service technicians:

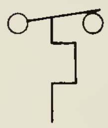
TEMPERATURE ACTUATED COMPONENTS

(Note: Symbols shown to be used for thermostats, bimetal switches, overload protectors, or other similar components, as required.)

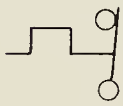
Temp. Actuated
(Close on Heat Rise)



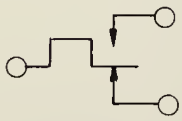
Temp. Actuated
(Open on Heat Rise)



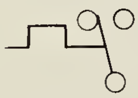
S.P.S.T.
(Open on Heat Rise)



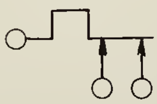
S.P.D.T.



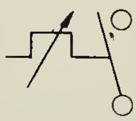
S.P.D.T.



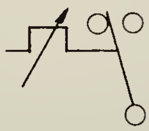
S.P.S.T.
(Two Contacts)



S.P.S.T. (Adj.)
(Close on Heat Rise)

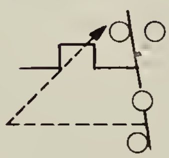


S.P.D.T. (Adj.)

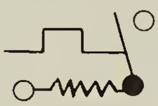


S.P.S.T. (Adj.)
(Open on Heat Rise)

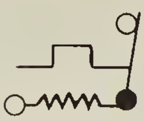
S.P.D.T. (Adj.)
(With Aux. "OFF" Contacts)
(Typical Example)



S.P.S.T. (w/Internal Heater)
(Close on Heat Rise)

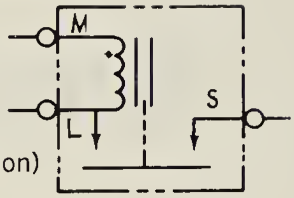


S.P.S.T. (w/Internal Heater)
(Open on Heat Rise)

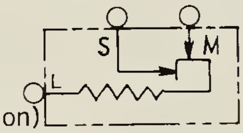


COMBINATION DEVICES

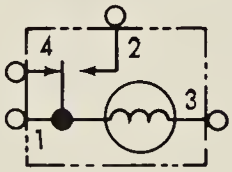
Relay-Magnetic
(Arrangement of Contacts
as Necessary to Show Operation)



Relay-Thermal
(Arrangement of Contacts
as Necessary to Show Operation)

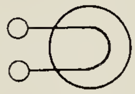


Timer (Defrost)

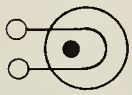


LIGHTS

Incandescent



Germicidal



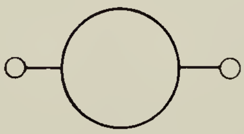
Neon

Fluorescent

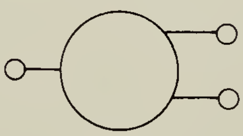
MOTORS

Timer Motor

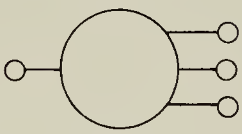
Single-Speed



Two-Speed

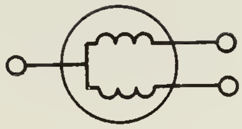


Three-Speed

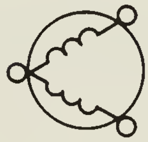


MOTORS

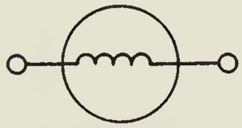
Note: Internal Motor Circuitry May Be Shown if Required.



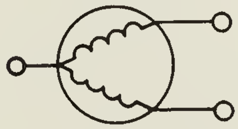
Compressor Motor



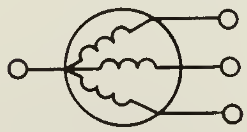
Single-Speed Motor



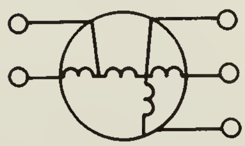
Two-Speed Motor



Three-Speed Motor



Multi-Speed Motor (Show Internal Circuitry as Req'd)

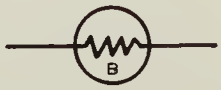


(Typical Example)

MISCELLANEOUS

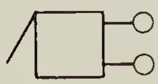
Auto. Starter

Ballast



Bell

Buzzer



Capacitor (Polarity Must Be Correct)

MISCELLANEOUS

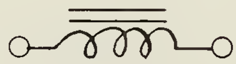
Circuit Breaker

Coil (Solenoid)

Coil

NOTE: COILS MAY ALSO BE SHOWN WITH OPEN LOOPS AS IN THE EXAMPLES BELOW.

Coil (Solenoid)



Coil

Fuse

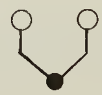
Heater or Resistor

Humidistat

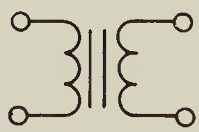
Relay

Use Symbols for Coil and Switches and Show Separately in Circuit.

Thermocouple



Transformer



Adjustable Component (Arrow Drawn Through Component at Approximately 45°)

LINES AND CONNECTIONS

Integral Conductor

Harness Wire

Crossover 

Crossover 

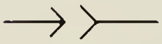
Shield

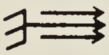
Permanent Connection 

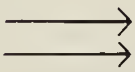
Terminal 

Ground (Earth) 

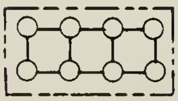
Ground (Chassis) 

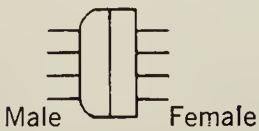
Plug Connector 

Grounded Service Cord (3-prong) 

Service Cord (2-prong) 

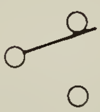
Mechanical Connection

Terminal Board (Number and Arrangement as Required) 

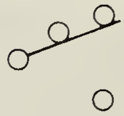
Multiple Connector (Engaged) 

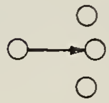
MANUAL AND MECHANICAL SWITCHES

S.P.S.T. 

S.P.D.T. 

MANUAL AND MECHANICAL SWITCHES

S.P.D.T. (2 Contacts on One Side) 

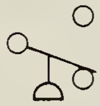
Multi-Position 

Push-Button (N.O.) (Momentary Contact) 

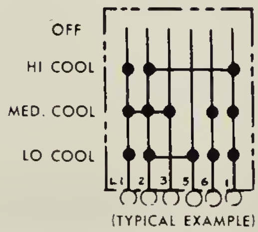
Push-Button (N.C.) 

Push-Button (Two-Circuit) 

Timer Switch 

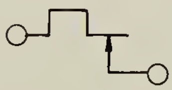
Pressure Operated (S.P.D.T.) 

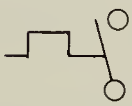
Centrifugal Switch 

Master or Control Sw. (Number of Positions and Internal Contact Operation as Required) 

TEMPERATURE ACTUATED COMPONENTS

(Note: Symbols shown to be used for thermostats, bimetal switches, overload protectors, or other similar components, as required.)

S.P.S.T. (Open on Heat Rise) 

S.P.S.T. (Close on Heat Rise) 

SOLID-STATE DEVICES

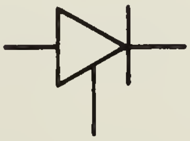
Solid-state devices are being used in modern home appliances. When required, the function of these devices is explained in the training program covering the product in which they are used. The solid-state devices shown below are some of the more common ones being used in appliances today.

Thermistor

Transistor (PNP)

Diode (Rectifier)

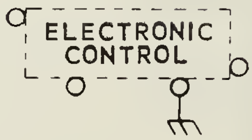
Rectifier (Controlled)



Silicon Controlled Rectifier (SCR)

Triac

Electronic Dryer Control



Sources of information

APPENDIX

F

If you are interested in learning more about the opportunities of a career in appliance service, further information and helpful material can be secured through your public school vocational counselors, local libraries, technical schools, gas and electric utility companies, and state employment service. Local business people and employers engaged in the service trade and the several trade associations connected with the appliance service industry can suggest other sources and perhaps furnish you with additional background information on training and employment opportunities and related facts. Groups which might assist you include:

Appliance Service News
5841 West Montrose Avenue
Chicago, Illinois 60634

Association of Home Appliance Manufacturers
20 North Wacker Drive
Chicago, Illinois 60606

National Appliance and Radio-TV Dealers Association
318 West Randolph Street
Chicago, Illinois 60606

National Appliance Service Association
1525 Broadway
Kansas City, Missouri 64108

National Association of Service Managers
4800 North Milwaukee Avenue
Chicago, Illinois 60630

Index

OTHER VOLUMES AVAILABLE IN THIS SERIES

SMALL APPLIANCE SERVICING GUIDE

Motor-driven and Resistance-heated Appliances

By ROBERT SCHARFF

This well-illustrated volume covers the basic servicing techniques for such motor-driven appliances as electric fans, vacuum cleaners, floor polishers, mixers, blenders, can openers, knife sharpeners, sewing machines, electric typewriters, electric knives, water pulsers for dental hygiene, shoe polishers, shavers, and electric clocks. Among the resistance-heating devices, the author discusses the servicing of electric irons, toasters, automatic grills, rotisseries, coffee makers, electric blankets and heating pads, electric space heaters, and personal care appliances.

MAJOR APPLIANCE SERVICING

Laundry, Washing, Pumping and Waste Disposal Equipment

By ROBERT SCHARFF

For both technicians and beginners in the appliance maintenance field, this outsized, fully illustrated volume shows how to service major appliances such as laundry, washing, pumping, and waste disposal equipment. It covers all the basic techniques for a wide variety of appliances—automatic washing machines and dryers, automatic dishwashers, water pumps and water softeners, heaters, food waste disposers, and trash compacters. This book, like all the other volumes in the series, was checked and rechecked for accuracy by the American Home Appliance Manufacturers Association.

REFRIGERATION, AIR CONDITIONING, RANGE AND OVEN SERVICING

By ROBERT SCHARFF

Practical, dependable, and completely up to date, this volume covers the servicing and repairs of such appliances as refrigeration systems, refrigerators, freezers, room air conditioners, dehumidifiers and humidifiers, electronic air cleaners, water coolers, central vacuum cleaning systems, and electrical ranges and ovens. It is an ideal guide for those who are working in general servicing areas and who wish to advance to field technicians, for it not only describes how appliances operate, but examines basic problem areas, and provides trouble-shooting techniques to solve problems.

ABOUT THE AUTHOR

ROBERT SCHARFF is a regular and frequent contributor of "how to" articles to leading magazines. A McGraw-Hill author for 25 years, he has written more than 100 books, including those described here. Other highly regarded works by Mr. Scharff include *The Complete Book of Wood Finishing, 2nd ed., The Complete Book of Home Remodeling*, and *More Plywood Projects for the Home Craftsman.*

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